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THE EFFECTS OF HEATED WATER DISCHARGE UPON LAKE WHITEFISH (*Coregonus clupeaformis* (Mitchill)) IN LAKE WABAMUN, ALBERTA

by

© Gary Richard Ash

A THESIS

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "The Effects of Heated Water Discharge Upon Lake Whitefish (<u>Coregonus clupeaformis</u> (Mitchill)) in Lake Wabamun, Alberta" submitted by Gary Richard Ash in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

Lake Wabamun has two thermal electric generating stations situated upon it which utilize lake water for cooling purposes. During the period June, 1972, to September, 1973, samples of lake whitefish were collected from the area of the heated water discharge from the Wabamun power plant and from a site in the west end of the lake, not influenced by the heated water discharge. Feeding habits, length-weight relationships, condition factors, gonadosomatic indices, and fecundity-to-length and fecundity-to-weight relationships of the whitefish from the two areas were compared statistically to determine differences which could be related to the heated water discharge. The standing crop of benthic invertebrates and of zooplankton from the two areas were sampled and the data related to the feeding habits of the whitefish.

During the fall of 1972 and 1973, the duration of the spawning period and the areas of concentrated spawning were determined. Lake whitefish egg survival was determined for eggs incubated _in situ_ in enclosed trays on natural spawning areas and also on various substrates in both the heated and non-heated areas. The effects of substrate type, water temperature, and siltation on egg survival and its relation to the heated water discharge areas are discussed.

Limited information on lake whitefish movements as determined by a tag and recapture method is also given.

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INTRODUCTION

The amount of leisure time available to the public over the past few decades has greatly increased. This, along with the concentration of large numbers of people into urban centers has created a demand for convenient recreational areas. The development of large urban centers and increased industrialization has also created a great demand for electrical energy. This has led to the construction of additional power plants. In Canada, most power plants either utilize water from reservoirs to power turbines or they use lakes or rivers as a source of cooling water for thermal electric units. Unfortunately, recreational uses often conflict with industrial uses.

Lake Wabamun (Figure 1), situated approximately 64 km west of Edmonton, is popular for sport fishing and other recreational uses due, in part, to its close proximity to a large population center. The lake also has two thermal electric generating stations situated on it which utilize the lake water for cooling purposes.

A number of studies have been undertaken to determine the effects of the heated effluents on the biota of Lake Wabamun. These include Wheelock (1969) dealing with the effects on phytoplankton ecology, Horkan (1971) on rotifers, Klarer (1973) on epiphytic algae and Allen (1973) on

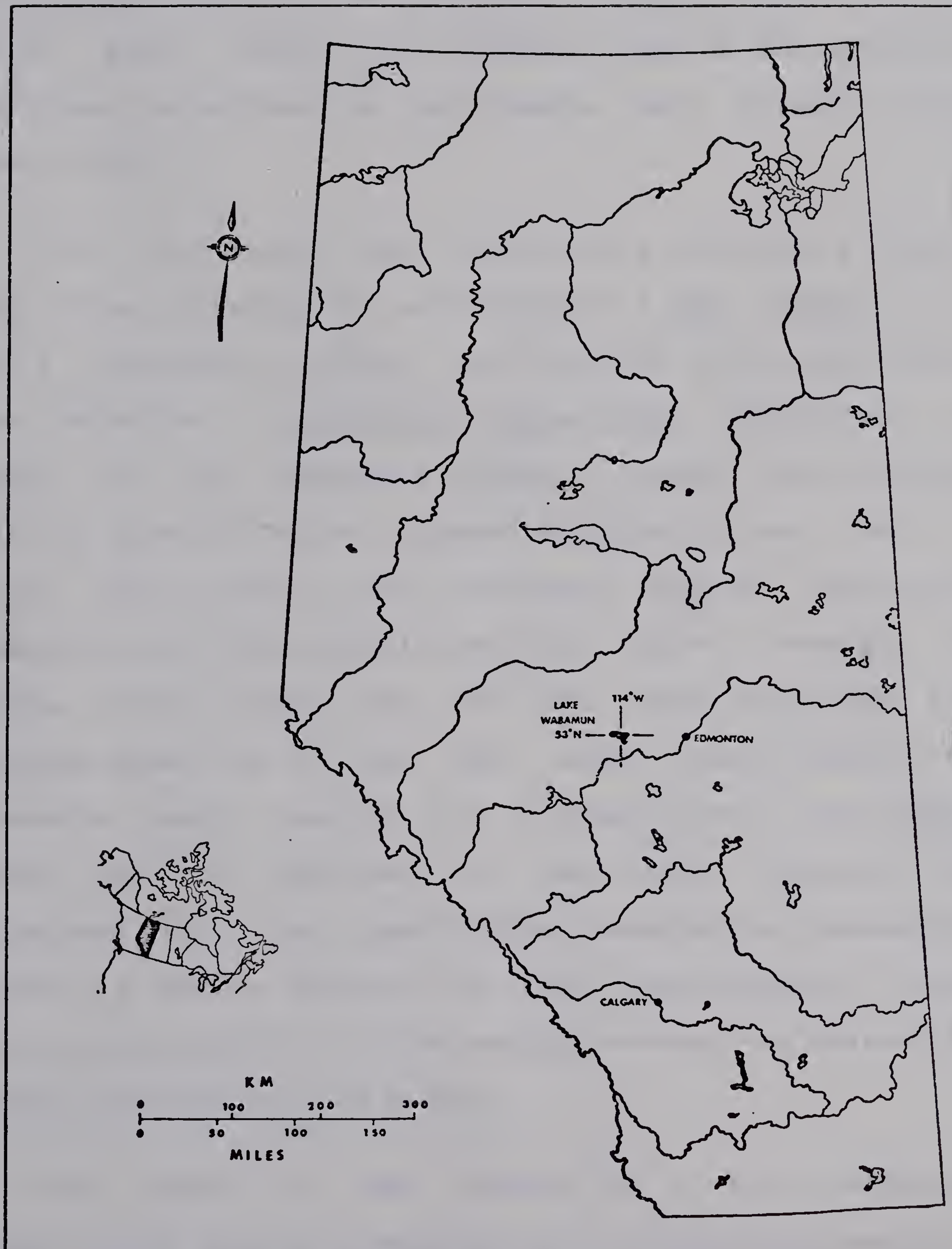

Figure 1. Map of Alberta showing the location of Lake Wabamun.

submerged macrophytes. Other biological studies on the lake include Nursall and Gallup (1971), Nursall et al (1972), Gallup (1971), Gallup and Hickman (1973), Klarer et al (1973), Noton (1973), and others. Much of the available literature is reviewed in The Alberta Lake Wabamun Study (Anon. 1973).

Over the years, Lake Wabamun has supported a summer sport fishery, mainly for northern pike (Esox lucius L.), and a commercial fishery, the majority of the take being lake whitefish (Coregonus clupeaformis (Mitchill)). A summary of the commercial fishing harvest (1944 through 1973) is given in Table 1. Within the past fifteen years a winter sport fishery has developed, placing additional demands on the fish populations. This fishery consists of angling both through the ice (for lake whitefish and northern pike) and in the open water areas around the discharge canals (mainly for northern pike). Lane (1970) points out the importance of this sport fishery. He calculated that the sport harvest exceeded the commercial harvest by 243% in 1968-69, and that approximately 44,000 people participated in winter angling whereas the commercial fishery involved only 52 people.

The fishery in Lake Wabamun is a very important resource both from an economical and recreational viewpoint. Lake whitefish, unlike the pike, are fall spawners and require low water temperature over the winter for successful

TABLE 1. Commercial Fishing Harvest (in pounds), Lake Wabamun, 1944 through 1973. (from Alberta Fish and Wildlife, Edmonton, Alberta)

SEASON	LAKE WHITEFISH	PIKE	PERCH[5]	MIXED	LING[6]	SUCKER[7]	TOTAL
44/45	318,201	700					318,901
45/46	338,400	500					338,900
46/47	532,779		844				533,623
47/48	369,117						369,117
48/49	300,530						300,530
49/50	277,615	8,105					285,720
50/51	300,397	6,188		6,494			313,079
51/52	248,558	8,069		3,163			259,790
52/53	138,645	2,728		1,364			142,737
53/54	198,893	1,824		390			201,107
54/55	403,465	1,640					405,105
55/56	1,056,000	375					1,056,375
56/57	451,743	1,020					452,763
57/58	334,095	2,665		1,400			338,160
58/59	250,280	56,526		35,368			342,174
59/60	121,430	43,215		12,654			177,299
60/61	126,390	44,229		15,253			185,872
61/62	CLOSED SEASON						
62/63	3,180	1,070		860			5,110
63/64	7,065	840					7,905
64/65	CLOSED SEASON						
65/66	90,000	1,650		1,000			92,650
66/67	23,000	250			680	400	24,330
67/68	52,102	1,208	10		1,125	1,717	56,162
68/69	45,671	5,272			3,930	3,596	58,469
69/70	55,898	1,919			7,590	6,516	71,923
70/71	40,022	7,488			2,610	6,320	56,440
71/71	52,858	3,346			1,927	5,304	63,435
72/73	105,401	7,991			5,632	14,677	139,701
TOTAL	6,241,735	208,818	854	77,946	23,494	38,530	6,591,377

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[5] *Perca flavescens* (Mitchill)
[6] *Lota lota* (L.)
[7] *Catostomus commersoni* (Lacepede)

egg incubation (Price, 1940). Fears have therefore been expressed as to what effect the heated effluents from the power plants have upon the reproductive and general biology of the whitefish. The aim of this study was to attempt to elucidate some of the effects of the heated water discharge on the feeding, growth and reproduction of the lake whitefish.

DESCRIPTION OF THE STUDY AREA

Lake Wabamun is a relatively large, shallow, eutrophic lake located approximately 64 km (40 miles) west of Edmonton, Alberta (Figure 1). Its geographic coordinates are 114° 26' to 114° 44' west longtitude, and 53° 30' to 53° 34' north latitude. Rutherford (1928) and Carlson (1971) give a good description of the geology of the surrounding area and Wyatt et al (1930) describes the soils of the area. Moss (1932, 1955) gives a description of the surrounding vegetation.

The morphometry of the lake as described by Nursall and Gallup (1971) is given in Table 2. A hydrographic map of Lake Wabamun is shown in Figure 2.

Two thermal electric generating stations are located on the lake (Figure 2). The Wabamun plant, located at the town of Wabamun, commenced operation in 1956 and now has a generating capacity of 600 megawatts (Mw). The Sundance plant (Plate 1), located on the west shore of Indian Bay began operating in late 1970 and at present also has a generating capacity of 600 Mw. Each plant utilizes 300,000 Imperial gallons of water per minute (IGPM) for cooling purposes from May to October. During the winter approximately half this amount is circulated.

Table 2. Morphometry of Lake Wabamun

(Data from Nursall and Gallup, 1971)

Elevation	722.7	m
Area (A)	82.5	Km^2
Volume (V)	ca. 0.455	Km^3
Length (l)	19.2	Km
Maximum breadth	6.6	Km
Mean breadth (b)	4.3	Km
Maximum depth (zm)	11.6	m
Mean depth (z)	5.4	m
Shoreline length (L)	57.3	Km
Shoreline development (Dl)	1.83	
Area of surface drainage	372.4	Km^2

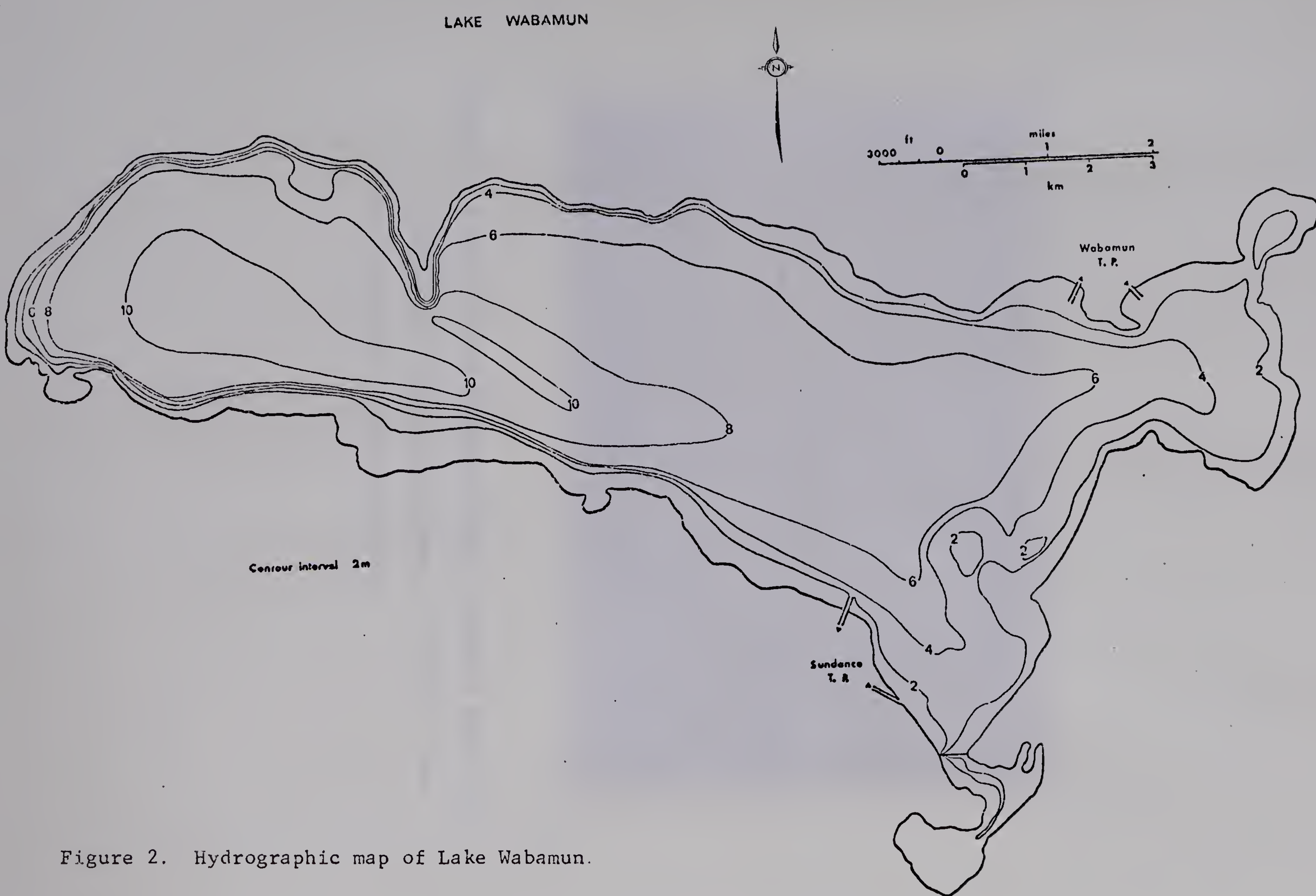

Figure 2. Hydrographic map of Lake Wabamun.

Plate 1. A photo of the Sundance thermal electric generating station taken during the winter of 1972-73. Note the open water area and the fog.

At present, two additional 375 Mw units are under construction at the Sundance plant and are expected to start production of electricity by 1978. Construction of a 1,200 acre cooling pond is also underway. Upon completion, the pond will be used as the source of cooling water for the Sundance plant, thereby eliminating any direct use of the lake for cooling purposes at this station.

MATERIALS AND METHODS

I Physical and Chemical

The substrate types of the lake were determined in various ways. Bottom samples were taken at various locations using a six inch (15.24 cm) Ekman dredge. The samples were examined and the substrate type recorded. SCUBA and snorkel diving were used in some areas, allowing direct observation of the bottom. In addition, the Alberta Fish and Wildlife Division (Edson Regional Office) made available samples of the substrate collected by their personnel during 1971.

Maps showing the depth contours were redrawn with some corrections from maps of hydrographic soundings made by the Alberta Department of the Environment, Water Resources Branch.

Temperatures throughout the water column were taken using a Whitney electric thermometer[1].

Dissolved oxygen measurements were taken in Goosequill Bay on January 28, 1974 after dead fish in the area had been reported. The azide modification of the Winkler method was used in determining the concentrations of dissolved oxygen.

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[1] Montedoro Corp. San Luis Obispo, California.

No dissolved oxygen measurements were taken in the remainder of the lake for the duration of the study since previous data collected by Gallup and Hickman (1973) and Klarer et al (1973) showed that the dissolved oxygen concentrations remained relatively high all year.

II Biological

Two sampling sites were set up (Figure 3) to determine the effects of heated water discharge upon the lake whitefish; one called the 'Warmwater' site (abbreviated WW) in front of the Wabamun discharge canal, and the other, the control site called the 'Coldwater' site (abbreviated CW), was located near Fallis.

Samples of lake whitefish were obtained during the period May, 1972 to June, 1973, by using gill nets (Plate 2) with streatched mesh sizes of 1.5 inch (3.81 cm), 2.5 inch (6.35 cm), 3.5 inch (8.89 cm), 4.5 inch (11.43 cm), and 5.5 inch (13.97 cm). At each gill net set, the water temperature, mesh size (stretched measure), meshes deep, length of each gill net, the time and date of the set, and the location of the set were recorded on catch record sheets. The number of each species captured and the duration of the set were recorded upon retrieval of each net.

For each whitefish, the following data were recorded: fork length to the nearest 0.1 cm, total weight to the

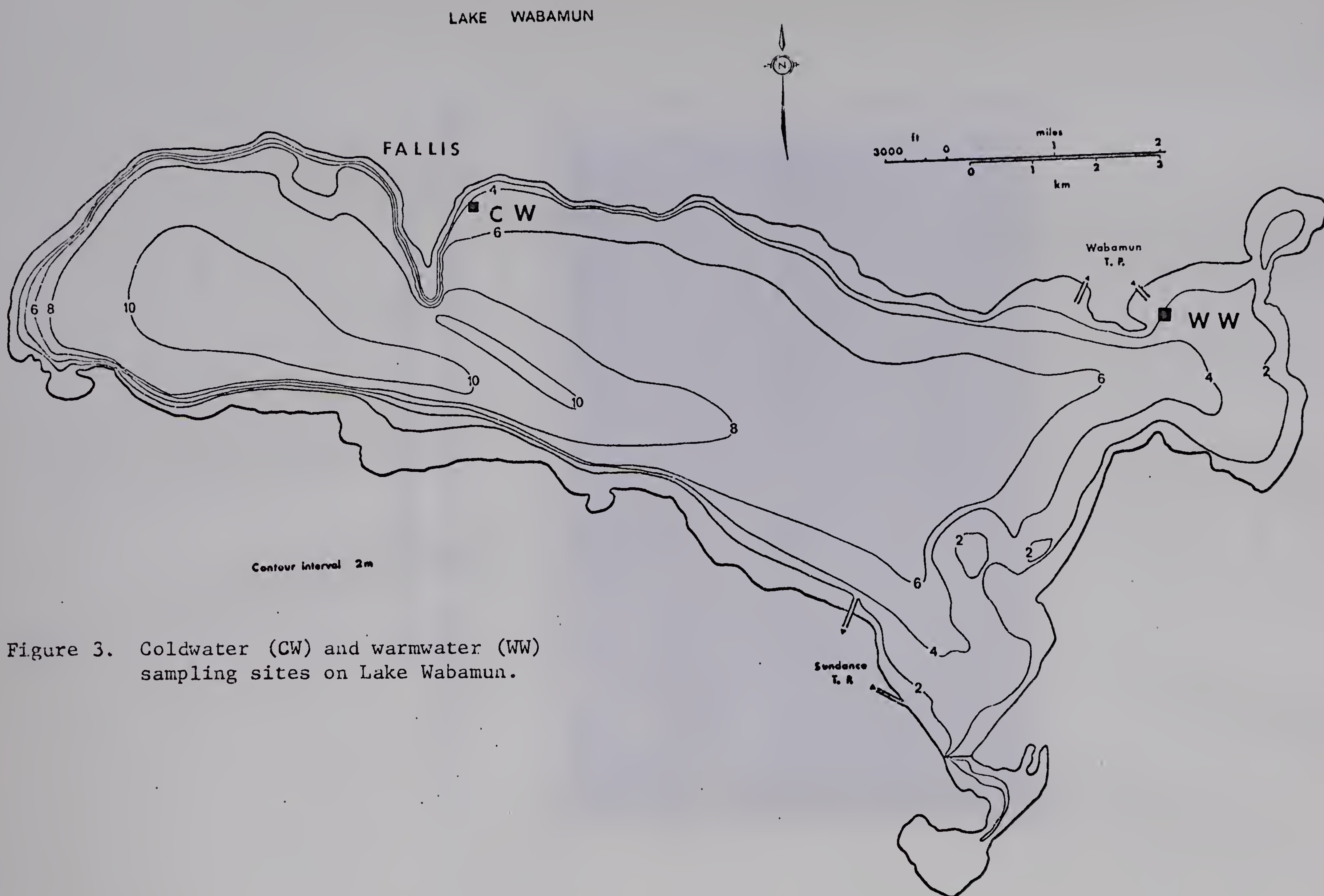

Figure 3. Coldwater (CW) and warmwater (WW) sampling sites on Lake Wabamun.

Plate 2. A gill net being pulled. This net was set on the spawning grounds on October 18, 1973.

nearest 0.1 g, and the sex and the state of maturity of the gonads. The method used to determine the state of maturity according to the appearance of the gonads was similar to that described by Bidgood (1972). Using his method, the fish were assigned to one of five categories. Immature fish had only a ribbon of gonad tissue and were not sexed. Maturing fish had definite gonad development and could be sexed. Mature fish had larger gonads which occupied the entire length of the coelomic cavity but did not freely emit eggs or sperm through the genital opening when external pressure was applied to their abdomen. Ripe individuals freely emitted eggs or sperm when slight pressure was applied to the abdomen. Spent individuals had flaccid gonads with the majority of the eggs absent in the females and the size of the testes reduced in the males.

The ovaries from the female fish (except for the immatures) were dissected out of the carcass and, after blotting on a paper towel to remove the excess moisture, were weighed to the nearest 0.1 g.

A sample of scales for age determination was taken from the left side of each fish from a position slightly anterior to the dorsal fin. The scales were mounted between acetate slides and viewed on an Eberbach microprojector. Due to the greatly inconsistent results when attempting to age the older fish, only the fish 4 years old or younger were aged in samples taken before May, 1973 and only those 5 years old

and younger were aged in samples taken during ane after May, 1973. The 4 year old fish before May and the 5 year old fish after May, 1973 represent the 1968 year class which could be recognized by a relatively wide band of growth on the scales during late 1972 and early 1973.

Otoliths were removed from a sample of fish in June of 1972 and stored in glycerine. The otoliths were studied in an attempt to verify the age as determined from scales. However, they were too opaque for counting of the growth rings and so were not used.

The stomachs of the fish were removed and placed in jars labelled as to sampling station, date and the 5 cm size class to which the fish belonged. Ten percent formalin was used as a fixative. At a later date the contents of the stomachs were placed into petri dishes and analysed using the method described by Thompson (1959) which is a modification of the method used by Hynes (1950). Upon being opened, each stomach was allotted points on a scale of 0 to 20 according to its degree of fullness. A full stomach was given 20 points, a half full stomach 10 points, and an empty stomach 0 points, etc. The size of the stomach was not considered since it was assumed that a full stomach is just as important to a small fish as it is to a larger one. After the fullness points were allotted to each stomach, the points were then distributed among the individual food items present according to their volume in relation to the volume

of the stomach contents. The food items present were identified with the aid of Pennak (1953), Usinger (1968) and Ward and Whipple (1959).

An estimate of the fecundity of the female lake whitefish was obtained from samples caught at both the warmwater and the coldwater sites between September 25 and October 10, 1973. The fork length, weight, and total ovary weight (to the nearest 0.1g) were noted for each fish. Two subsamples of eggs taken from the anterior, mid and posterior areas of both ovaries were weighed to the nearest 0.001g. The total number of eggs in each subsample was recorded. The fecundity was calculated by the following formula:

$$\text{FECUNDITY} = \frac{\text{number of eggs in the subsample X ovary weight}}{\text{weight of the subsample}}$$

The average fecundity obtained from the two subsamples was taken as an estimate of the fecundity for the fish.

It was expected that the estimate of the fecundity would be larger than the true fecundity of the fish because of the blood vessels and the connective tissue in the ovary. To test this hypothesis and estimate the error and variability of error, total egg counts were performed on the ovaries from five fish. This was then compared to estimates of fecundity obtained from subsamples taken from the same fish.

To allow a comparison between the food eaten by the

lake whitefish and the standing crop of the food available at both the warmwater and the coldwater sites, the standing crop of bottom fauna and zooplankton was sampled between June 1972 and June 1973. The samples were taken once during June 1972, biweekly during the period July to August and monthly between September 1972 to June 1973 with the exception of November, February, and April, when no samples were taken. Water temperatures were recorded at each site on each sampling date. The water temperatures were taken at 2 foot (0.61 m) depth intervals with a Whitney electric thermometer.

The standing crop of bottom fauna was sampled with a 6 inch (15.24 cm) square Ekman dredge. The samples were washed in a screen bottom bucket (mesh aperture of 0.8 mm), and the contents placed into plastic bags. The contents were then examined in white enamel trays and the invertebrates picked out and preserved in 70% ethanol. The invertebrates were counted and identified using Pennak (1953), Ward and Whipple (1959) and Usinger (1968).

The standing crop of zooplankton was sampled by taking two vertical hauls at each site with a #20 Wisconsin type plankton net (mesh size of 80 u). The samples were placed into vials labelled as to the location, date, and the depth of the haul and were then preserved in a solution of 10% formalin. The samples were later transferred into 70% ethanol from which a one-tenth or one-twentieth (by volume)

subsample was taken, depending on the concentration of the zooplankton. The subsamples were placed into plastic petri dishes which had been marked off into eight counting sections. Three ml of a 50% mixture of glycerine and ethanol, colored with a drop of lignin pink, were added to the petri dishes and the alcohol allowed to evaporate overnight. This left the zooplankton suspended in the viscous glycerine/lignin pink mixture. The zooplankton were then counted in the following groups:

Cladocera

Daphnia spp.

Ceriodaphnia sp.

Alona sp.

Eurycercus sp.

Copepoda

Calanoid

Cyclopoid

Fifty specimens from each group were measured and the lengths were averaged. The average weight (in mg) of an individual in each group was then estimated using the formulae of Pechen (1965), Osmera (1966), and Klekowski and Shushkina (1966), as given in Edmondson and Winberg (1971). An estimate of the biomass of each group was calculated by multiplying the average weight of an individual by the total number of individuals in that group.

After counting and measuring, the samples were thoroughly examined and all of the species present were

identified using Ward and Whipple (1959), Brooks (1957) and Gurney (1931; 1933).

The species of fish present in the lake were determined from samples from gill nets, seine hauls, and dip nets, and from fish taken from weeds in Ekman dredge samples.

To determine the extent of the spawning period and the areas of concentrated spawning, gill nets were set at various locations throughout the lake and the fish captured were examined to determine if they had spawned. Ripe fish captured in the nets were taken to indicate probable spawning areas. Caution had to be used when interpreting these data since fish are very mobile and the ripe fish may have been moving to an area suitable for spawning when caught in the net. The date on which the first spent fish (i.e., one that had recently spawned) was caught was taken to be the start of the spawning period, and the date on which the last ripe fish was caught was taken to represent the end of the spawning period. However, since samples were taken infrequently and since the sample sizes were often small, the extent of the spawning period could be longer than indicated from this study.

Large concentrations of ripe fish were observed in the areas of the two thermal effluent discharge canals during the spawning periods of 1972 and 1973. To assess the extent to which lake whitefish spawn in these and certain other areas of the lake, bottom samples were taken in early

November of 1972 and between November 27, 1973 and January 9, 1974 using a 6 inch (15.24 cm) square Ekman dredge. The bottom samples were washed through a screen bottom bucket and then placed into plastic bags labelled as to sampling location. Each sample was examined and the number of lake whitefish eggs present was recorded. The identification of the eggs was greatly simplified by the fact that lake whitefish are the only fall-spawning fish in the lake. The heated area around the Sundance discharge canal was the most extensively sampled area in 1973 due to the large concentrations of fish noted in this area and the ease of access and ease of sampling from a boat in the open water area after freeze-up. Some samples were taken through the ice using a snowmobile or a four-wheel drive truck (Plate 3) for transportation. However, the number of these samples was limited due to the short period of time when the ice was safe to travel on and the snow depth was not too great. Flooding under the snow often prevented travel by snowmobile.

The Ekman dredge is only suitable for sampling soft substrates such as ooze or sand and is unsuitable for sampling rock or gravel substrates. An Edson pump[2] was used to suck up eggs from certain areas of rock and gravel substrate. This method was used only to a very limited extent since the data obtained was only qualitative and not

[2] Ralph H. Wilson, Co. Ltd., Edmonton, Alberta

Plate 3. The hazards of winter sampling. Why are sample sizes often small?

quantitative. Since whitefish favor rocky or gravel substrates for spawning (Hart, 1930) and since these areas could not easily be sampled quantitatively, the number of eggs spawned on, and thereby the importance of, each area was not determined.

To determine the effect of temperature, substrate type, and siltation upon the survival and hatching success of lake whitefish eggs, fertilized eggs were incubated in situ in enclosed trays at different lake sites. The egg incubation trays (Plate 4) were made by cutting ten inch (25.4 cm.) diameter PVC piping transversely into three-quarter inch (1.9 cm.) deep hoops with a band saw. Plastic window screening (aperture size of 1 mm.) was then fused to both the top and the bottom of the hoops with a soldering iron. A small portion of the screening on one side was not fused thereby leaving an opening through which the eggs could be introduced (Figure 4). Each tray was carefully checked to ensure that the screening was securely fused. Strings were attached to most of the trays allowing them to be lowered to the bottom of the lake and retrieved easily.

On October 19, 1973, eggs from five ripe female lake whitefish caught on the rocky shoal along the Indian Reserve were stripped into a clean plastic bucket (Plate 5) and then were fertilized with milt from a minimum of ten ripe males taken from the same net. The eggs and sperm were mixed thoroughly and let stand for ten minutes. The eggs were then

Plate 4. An enclosed tray that had been used to incubate lake whitefish eggs in situ in Lake Wabamun over the winter of 1973-74.

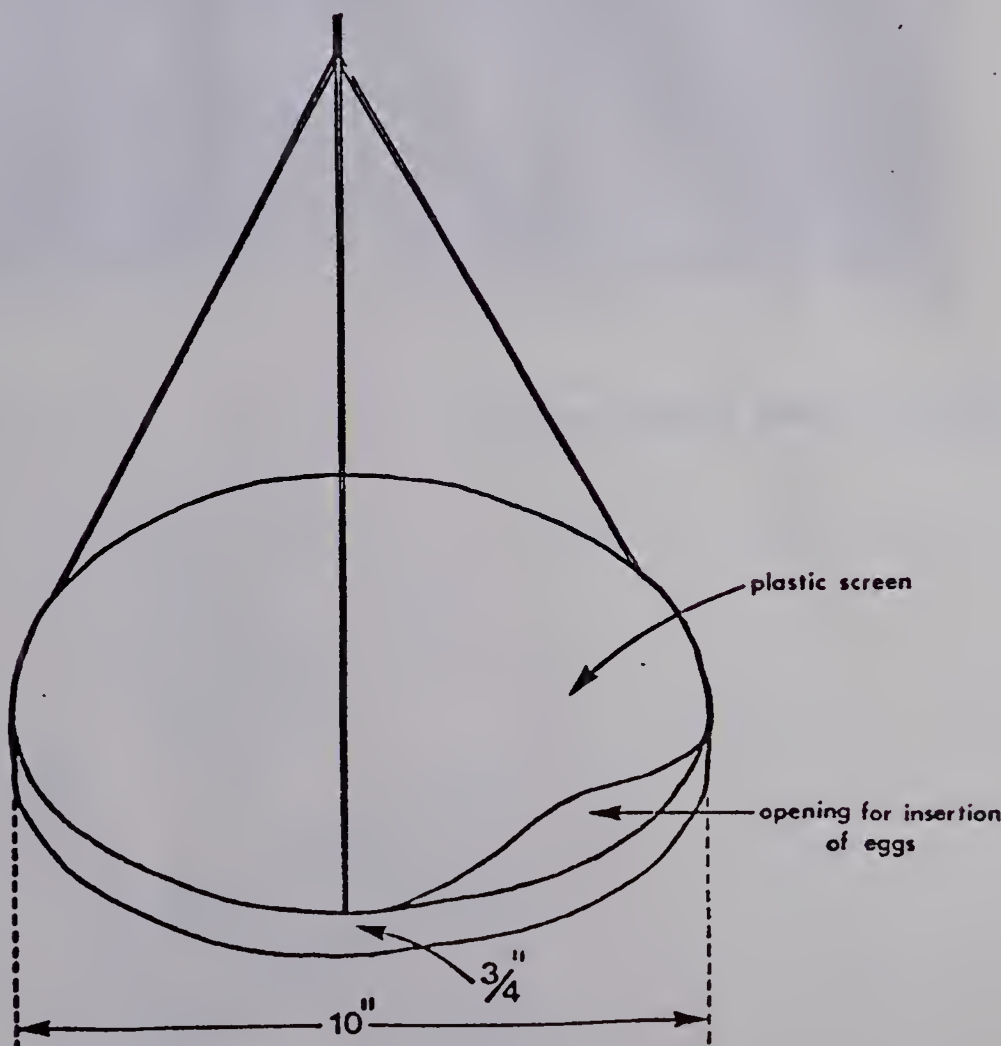

Figure 4. Egg incubation tray construction.

Plate 5. Eggs being stripped from a ripe female lake whitefish on October 19, 1973.

rinsed several times in lake water and allowed to water harden for one hour. Three samples of 15 ml of eggs were saved in individual jars for counting. Fifteen ml of eggs were poured into each of fifteen egg trays through the opening in the screening. The trays were sealed using an electric soldering iron. The filled trays were placed into buckets of lake water and transported to site IR1 (Figure 5) where they were lowered to the substrate. The strings were attached to an anchor which in turn was attached to a float on the surface. SCUBA diving was employed to ensure that all trays were on a flat surface so that the eggs would not be clumped along one edge of the tray. A thirty day recording thermograph[3] was attached to an anchor and lowered to the substrate. A buoy was used to mark the location. The temperature of the water column and the substrate was recorded using the Whitney electric thermometer.

The average number of eggs in each of the three 15 ml samples that had been collected earlier was taken to represent the approximate number of eggs in each of the egg incubation trays.

On November 15, 1973, eggs for a second set of incubation trays were stripped from twenty ripe females that had been caught in a gill net under the ice (Plate 6) at the CW site at Fallis. The eggs were fertilized, allowed to

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[3] Model D-30. Ryan Instruments Inc. Seattle, Washington.

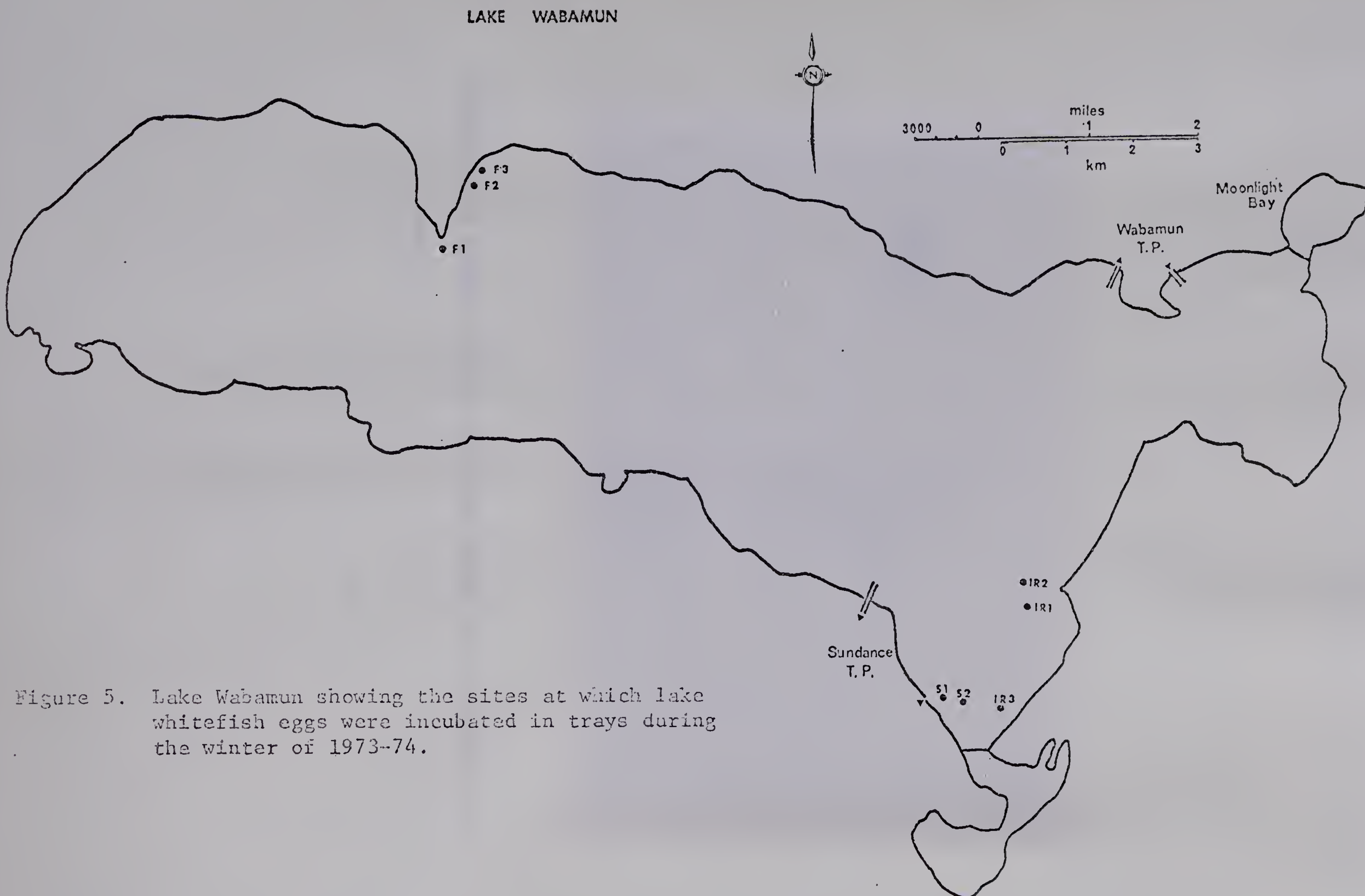


Figure 5. Lake Wabamun showing the sites at which lake whitefish eggs were incubated in trays during the winter of 1973-74.

Plate 6. A jigger used to set nets under the ice during the winter.

water harden and placed into the incubation trays using the method explained previously.

During the period November 15 to 17, 1973, twenty trays containing lake whitefish eggs were lowered to the lake bottom at each of the sites shown in Figure 5 with the exception of IR1 which was the site established on October 19. Site IR2 was the best estimate of site IR1 since IR1 had been lost due to ice and snow cover over the buoy. The depth and the substrate type at each site is shown in Table 3. The control sites (F1, F2, and F3) are characterized by different substrate types and were located in the portion of the lake that is not influenced by the heated effluents from the power plants. Sites S1 and S2 were in the open water area directly out from the Sundance thermal effluent discharge canal and both are characterized by an organic ooze substrate.

To test the effects of the ooze upon egg survival, an additional ten egg incubation trays were placed on top of empty trays that had been placed on the ooze substrate, thereby keeping the incubating eggs approximately 3/4 inch (1.9 cm.) above the substrate. Five of these trays were also covered by a piece of clear polyethylene supported above the trays on steel poles. The polyethylene was approximately 25 cm above the trays and thereby prevented silt in the water from settling on the eggs while still allowing some circulation of water over the eggs. The ten trays and the

Table 3. Substrate type and depth at the egg incubation sites.

SITE	DEPTH	SUBSTRATE TYPE
IR1	2.1 m (7 ft)	Rock, Gravel
IR2	2.1 m (7 ft)	Rock, Gravel
IR3	2.7 m (8.7 ft)	Sand
F1	1.9 m (6.7 ft)	Rock, Coal, Sand
F2	1.5 m (5 ft)	Sand
F3	1.4 m (4.5 ft)	Ooze
S1	2.1 m (7 ft)	Ooze
S2	2.4 m (8 ft)	Ooze

polyethylene were placed into position while SCUBA diving. Substrate temperatures were recorded at all of the sites when the trays were put into place. In addition, thirty day recording thermographs were placed on the substrate at both S1 and S2 to record the fluctuations in temperature.

Five incubation trays were retrieved each month from sites F1, F2, F3, IR2, S1 and S2 with the exception of S2 where no trays were retrieved in March of 1974. Five trays were retrieved from IR3 in December of 1973. This site was lost in January of 1974 when the ice in this area melted due to the increased heated water output associated with the starting of the second generating unit at Sundance. Site IR1 could not be located until March 1974 due to the ice and snow cover. Eight incubation trays were recovered in March from this site. At site S1 the five trays under the polyethylene and the five trays that were on top of the empty trays were retrieved by diving in Feburary of 1974. The charts in the recording thermographs at S1 and S2 were replaced each month. Temperatures were taken throughout the water column and the temperature of the substrate was recorded at each site before the egg incubation trays were retrieved.

The incubation trays retrieved were taken back to the laboratory, opened, and the number and state of development of the viable eggs was recorded. The extent of the fungal growths, the condition of the dead eggs and the

invertebrates found in the trays were also noted. Photomicrographs of the eggs were obtained using a 35 mm Zeiss Icarex camera adapted to a Wild M5 stereo microscope. The results were compared for the various treatments.

A total of fourteen lake whitefish fry were collected on April 25, 1973 in a trawl towed over the rocky shoal area in Indian Bay. The trawl consisted of a semicircular metal hoop (radius of 1/2 m) with plastic window screening (aperture of 1mm) tapering back to a metal bucket. The length and the stomach contents of the fry collected were recorded.

To determine the effects of heated effluents upon a species of fish, it is necessary to know something about the movements of the fish in and out of the heated areas. For this reason a fish tagging program was set up from September of 1972 to June of 1973 during which time 999 lake whitefish, 379 northern pike, 4 burbot and 46 white suckers were tagged. Plate 7 shows a tagged lake whitefish ready to be returned to the water. Of those fish tagged, 932 whitefish, 312 pike, all of the burbot and 5 white suckers were tagged at the small canal joining Goosequill Bay to the main part of the lake. As a consequence, very few data were obtained for fish moving into and out of the heated area, but rather, most of the data concern fish moving away from the canal where they were tagged. Tag return forms (Appendix 1) were distributed to the Alberta Fish and Wildlife

Plate 7. A tagged lake whitefish ready to be returned to the water. The tags used were numbered plastic 'spaghetti' tags with a 'T' anchor.

Division and to numerous fishermen in the area. All of the information regarding tag number, tagging location, length of the fish, as well as a scale sample from each fish has been turned over to the Alberta Lands and Forests Department, Fish and Wildlife Division.

Wilcoxon's two-sample test was used to statistically compare means obtained from data that were not normally distributed. Student's "t" test for unpaired observations, unequal variances and unequal sample size was used for the statistical comparisons of two means if they were obtained from normally distributed data. Regression equations were calculated using the method of least squares and two regression lines were compared using analysis of covariance to determine if the lines were estimates of the same population (Sokal and Rohlf, 1969).

RESULTS AND DISCUSSION

I PHYSICAL AND CHEMICAL

1. Morphometry

Lake Wabamun was arbitrarily divided into several regions (Figure 6). The bottom contour of the larger west portion of the lake slopes rapidly from the shoreline to a depth of 8 m and then gently slopes to 11.6 m which is the maximum depth of the lake. Kapasiwin Bay, located in the east end of the lake, is a relatively shallow area, the majority of it being less than 5 m in depth. Goosequill Bay is a shallow bay separated from the remainder of the lake by a railroad causeway. The only connection between the main part of the lake and this bay is via a channel that passes under a trestle in the railroad causeway. Indian Bay (Figure 6) is generally less than 6 m in depth, the greater part of it being between 2 and 4 m.

The majority of the lake is characterized by an ooze substrate (Figure 7). Rock and sand substrates are found dispersed around the perimeter of the lake generally in areas with less than 4 m of water. The major area with a rock substrate is the shallow east portion of Indian Bay.

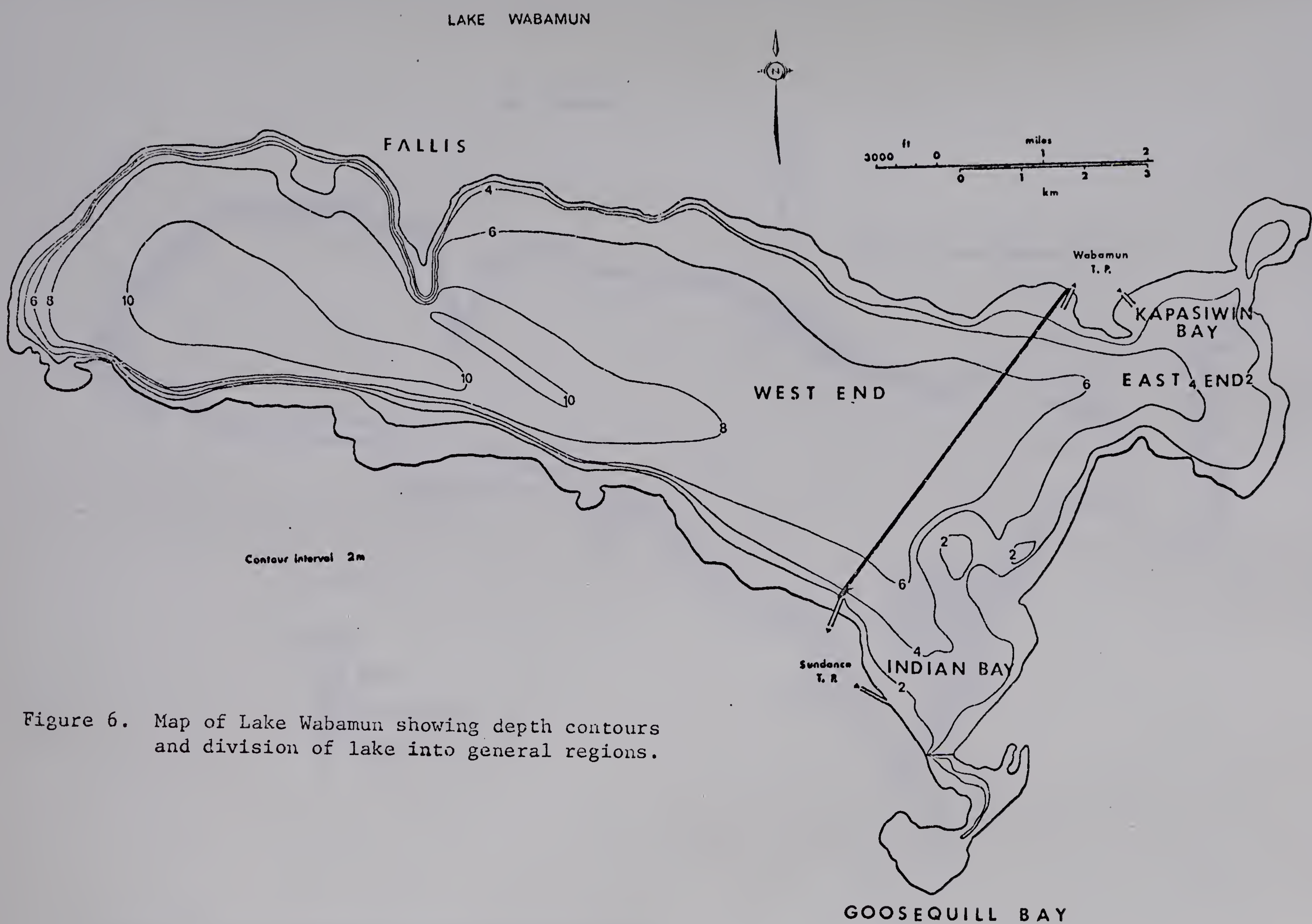


Figure 6. Map of Lake Wabamun showing depth contours and division of lake into general regions.

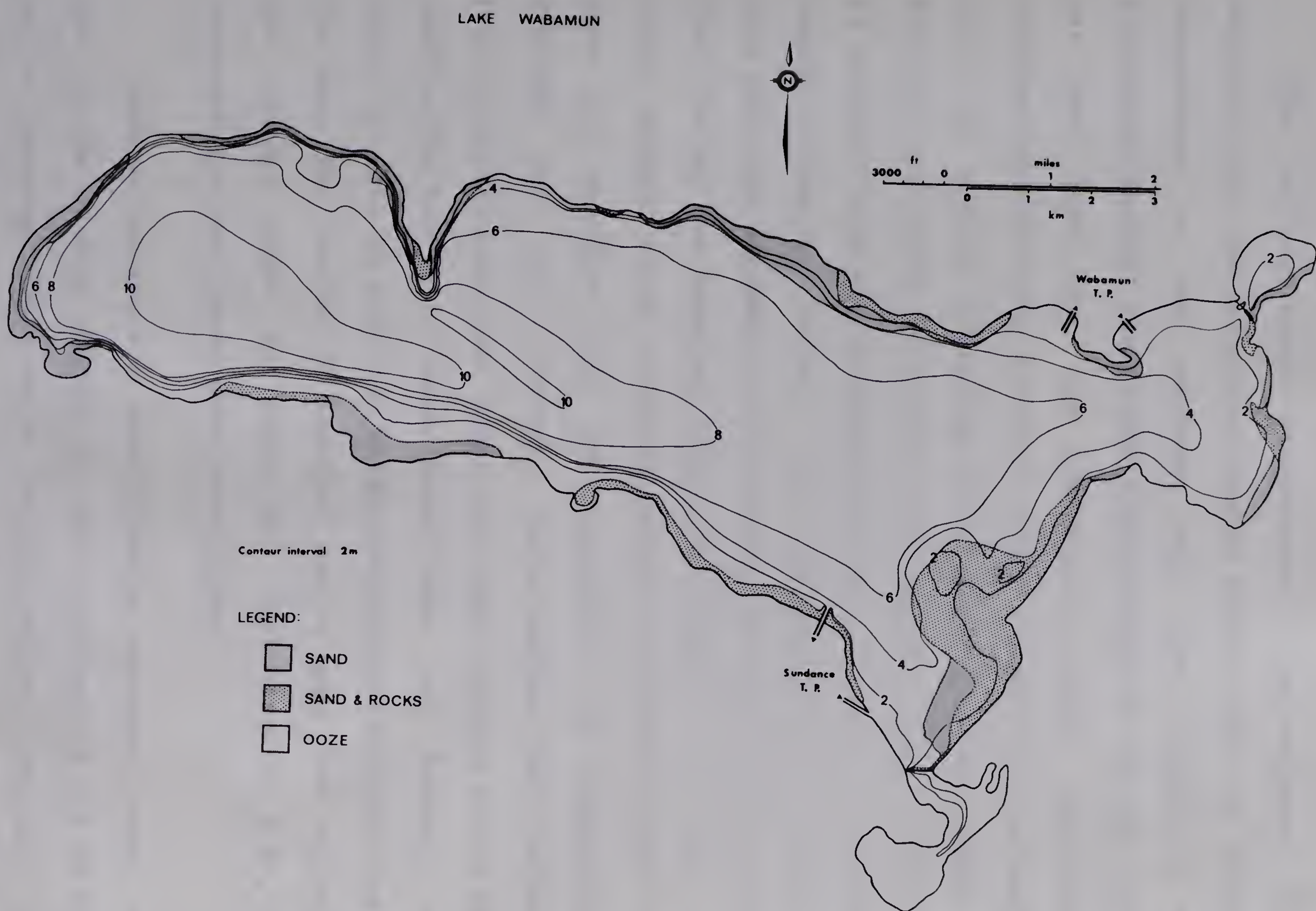


Figure 7. Lake Wabamun showing substrate types.

2. Temperature

The surface water temperature at the warmwater fish-sampling site (WW) was consistently higher than the surface temperature at the coldwater site (CW) (Figure 8). The difference between the bottom temperatures at the two sites was much less than the difference between the surface temperatures over the one year period (Figure 8) indicating that the heated discharge water (thermal plume) tended to float on the cooler water with only slight mixing. Since the WW sampling site was approximately 200 m from the Wabamun heated discharge outlet, the temperature of the water at this site was dependent on the direction and velocity of the wind. During the sampling period in February and March of 1973, strong winds were deflecting the thermal plume away from the sampling site and therefore the temperatures recorded were low. However, since samples (and therefore water temperatures) were taken only once a month during this period, the low water temperatures shown for February and March at the WW site are unrepresentative for that time of the year. Had the day of sampling been a calm day allowing the thermal plume to reach the fish sampling site, the temperatures would have been much higher.

Inverse temperature stratification occurred under the ice at the CW site (Figure 8). No ice formed at the WW site and no inverse temperature stratification occurred. The temperature difference between the surface water and the

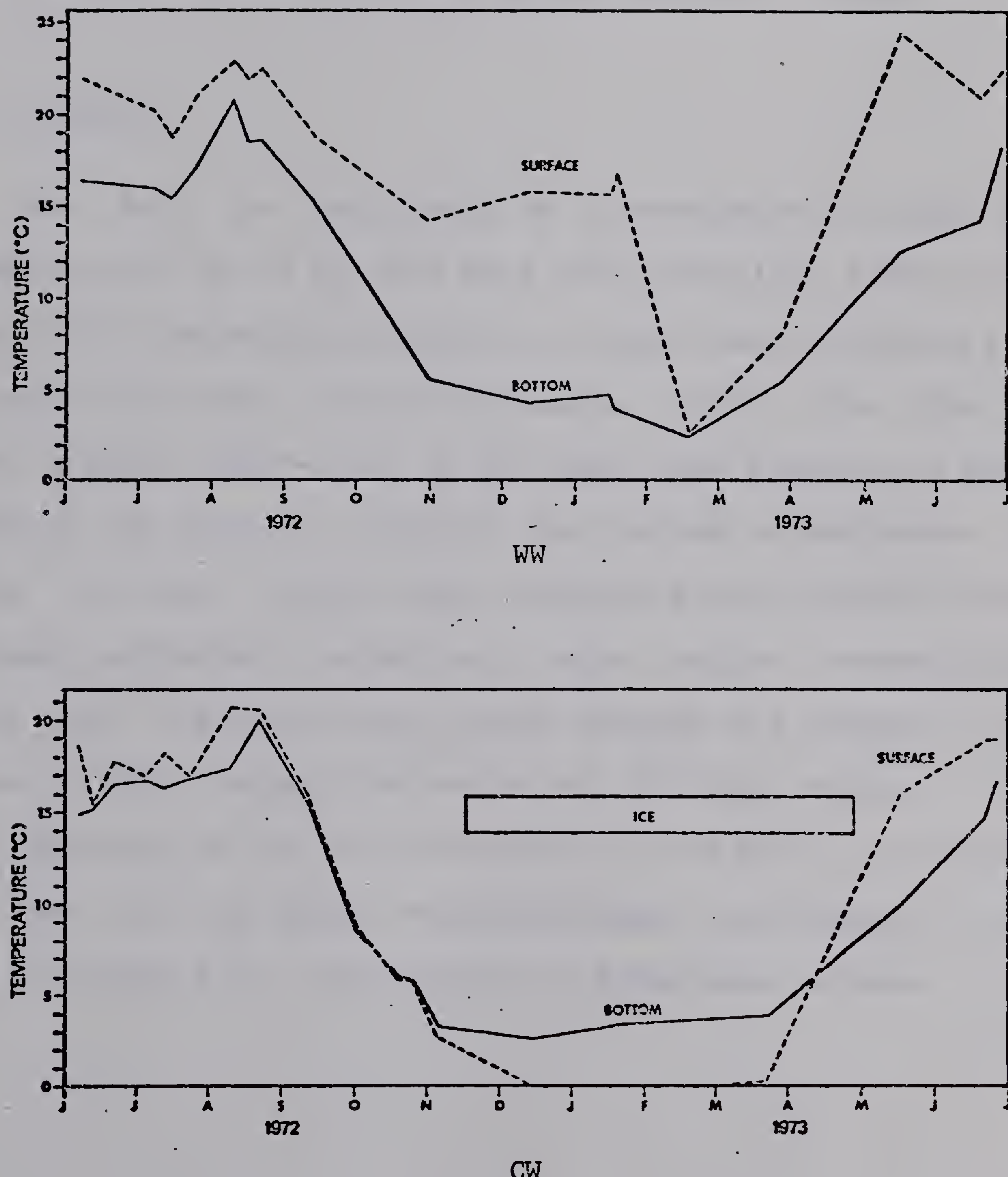


Figure 8. Water temperatures at both the WW and CW sampling sites.

bottom water at the WW site was much greater during the winter months than the summer months (with the exception of February and March as previously explained) again indicating the tendency of the heated water to float on the colder water with the density differences retarding mixing.

3. Oxygen

The lake is positioned in a north-west to south-east direction and so is in line with the prevailing winds of the area. Winds periodically result in large waves which mix and oxygenate the water. Also, the heated water from the two power plants keeps areas of the lake open during the winter (Plate 8 and Plate 9) allowing wind action to oxygenate the water in those areas. This, coupled with internal current systems, maintains a relatively high oxygen concentration under the ice during the winter (Gallup and Hickman, 1973; Klarer, 1973). During the winter of 1973-74, however, a fish kill occurred in the very shallow and productive Goosequill Bay due to low oxygen concentrations. Measurement in this area on January 26, 1974 showed no detectable oxygen.

Plate 8. Aerial photographs of the ice-free areas in front of the Wabamun power plant owing to the discharge of heated water from the plant.

A) January 20, 1974

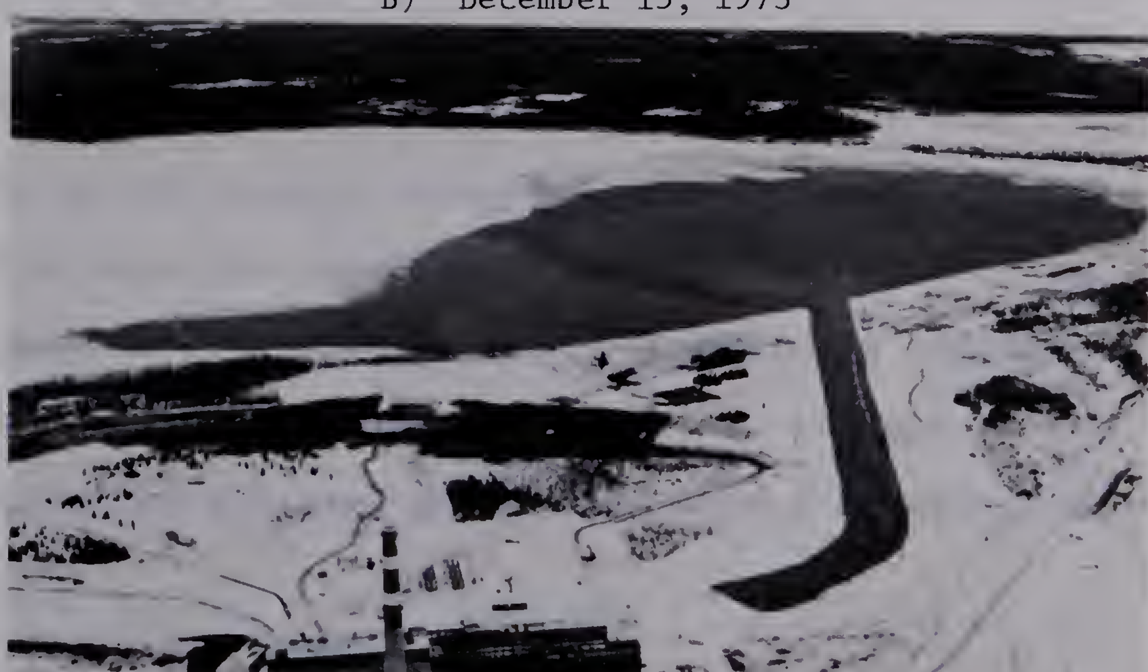
B) December 15, 1973

C) December 8, 1973

Plate 9. Aerial photographs of the ice-free areas in front of the Sundance power plant owing to the discharge of heated water from the plant.

A) December 8, 1973

B) December 15, 1973



C) January 20, 1974

II BIOLOGICAL

1. Fish Species

There have been 8 species of fish collected from Lake Wabamun (Table 4). The lake supports large populations of northern pike and lake whitefish which are the most important species in both the commercial (Table 1) and sport harvest. White suckers, spottail shiners and yellow perch are also found in large numbers. The majority of the perch, however, are stunted and only one specimen over 100g was collected during this study. Burbot, brook sticklebacks and Iowa darters appeared to be much less common.

2. Comparisons Of Data From The WW and CW Sites

In order for the thermal effluents to significantly affect whitefish growth and maturity, a group of fish must remain in the heated areas for considerable periods of time. If this were the case, comparisons of data from the two fish sampling sites should show significant differences. If, however, the whitefish were moving in and out of the heated areas, no significant difference should be detected.

Table 4. Species of fish collected from Lake Wabamun

SPECIES	
Lake Whitefish	_Coregonus_ _clupeaformis_ (Mitchill)
Northern Pike	_Esox_ _lucius_ L.
White Sucker	_Catostomus_ _commersoni_ (Lacépède)
Burbot	_Lota_ _lota_ (L.)
Yellow Perch	_Perca_ _flavescens_ (Mitchill)
Spottail Shiner	_Notropis_ _hudsonius_ (Clinton)
Brook Stickleback	_Culaea_ _inconstans_ (Kirtland)
Iowa Darter	_Etheostoma_ _exile_ (Girard)

A. Feeding Habits and Food Availability

The diets of the lake whitefish at the two sites compared over a thirteen month period were quite different (Figure 9). The whitefish at the CW site ate a larger percentage of Tendipedidae larvae and pupae throughout the year than did the fish at the WW site. During the period September to January, Tendipedidae made up less than 5% of the diet of the whitefish in the warm water. Pelecypoda were also very important in the diet of fish at the CW site, but were eaten only sparingly by the fish at the WW site. Cladocerans were present in significant numbers in the samples at the CW site only during May, June and July, whereas at the WW site they were significant in the diet in the winter months as well as during the spring and early summer of 1973. It appears that during the winter, the warm open water area was suitable for the adult cladocerans to feed and reproduce, whereas the majority of the cladocerans in the cold water wintered under the ice as ephippial eggs. Ephippial eggs were found in fairly high numbers in the stomachs of CW fish during the winter, probably being picked up by accident as the fish were feeding on other benthic invertebrates. However, due to their small size, ephippial eggs never contributed more than 5% by volume of the stomach contents so are shown as part of the miscellaneous.

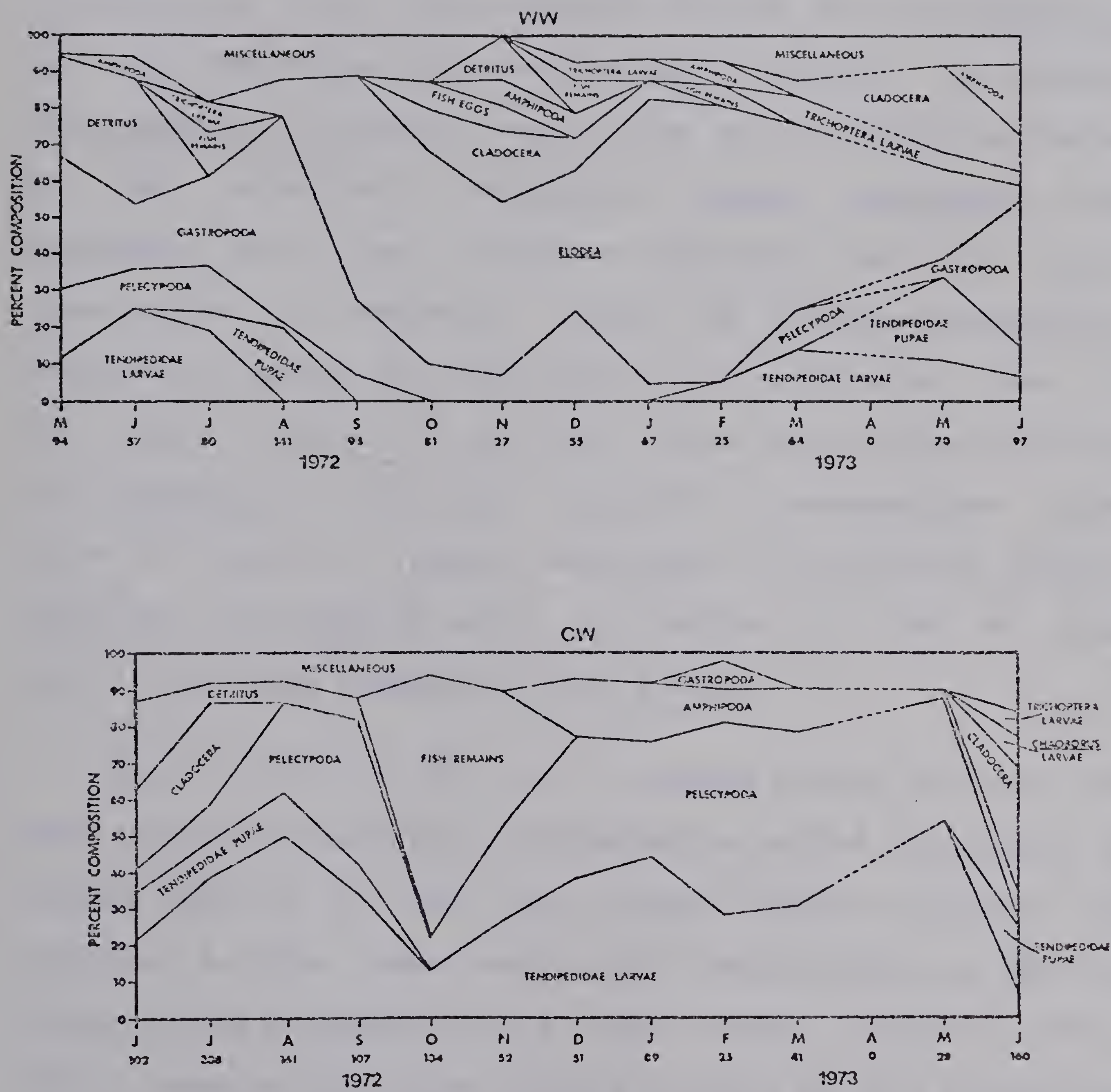


Figure 9. Percentage composition of food items in the diet of lake whitefish at the WW and CW sampling sites over a 13 month period. Data from fish sampled between June, 1972 and June, 1973. Sample sizes are shown below the size class.

Trichopteran larvae appeared in the diet in significant numbers (>5%) throughout much of the year in the WW samples but contributed only greater than 5% of the diet of CW fish during June of 1973. This is explained by the fact that the trichopteran most often eaten at the WW site was *Oxyethira* sp. These organisms are found in large numbers in clumped distributions throughout much of the year attached to leaves of the submerged macrophyte *Elodea canadensis* (Joe Rasmussen, pers. comm., 1974) and therefore they are quite susceptible to predation. Since the submerged macrophyte numbers and growth are much less in the cold water than in the heated portion of the lake, there is much less habitat for *Oxyethira* sp. and other epiphytic invertebrates. Thus there is also a larger occurrence of gastropods (mainly *Physa* spp. and *Valvata* spp.) in the diet of the WW fish than in the fish sampled at the CW site.

Lake whitefish fed to a limited extent on their own eggs during the spawning and incubation period. Eggs made up greater than 5% of the food volume during October and November in the warm water, but contributed less than 5% during the same period in the cold water. Bidgood (1972; 1973) reported whitefish feeding on eggs in both Pigeon and Buck lakes. In Pigeon Lake, he found whitefish eggs to be making up approximatly 70% of the diet of the whitefish during November with lesser amounts being eaten in December and January. He also reported that during March, fish eggs (mainly burbot eggs) were again the major constituent of the

diet.

Fish were the predominant food eaten by the whitefish at the CW site during October and November. At the WW site, fish were eaten in quantities sufficient to contribute to over 5% of the diet only during the months of July, December and February. Yellow perch (Perca flavescens (Mitchill)) was the only species of fish identified in the stomachs. The explanation of the sudden shift of the CW whitefish to eating large numbers of perch is not known. It may be that the small perch and the whitefish are to some extent separated during the summer months with the whitefish inhabiting the colder, deeper areas of the lake and the newly hatched perch living in the shallow shoreline areas. During October and November, however, the whitefish move into the shallow areas to spawn and at the same time, the small perch may be moving into deeper water for the winter or possibly concentrating on the whitefish spawning areas to feed on the whitefish eggs. The period of time when the small perch and the whitefish come together may give the whitefish a chance to prey upon them. Since small perch were observed in large numbers in weedy areas at the WW site during the summer, the opportunity for the whitefish to prey on these perch would be greater throughout the year in this area. This is exemplified by the occurrence of perch in the diet of the WW whitefish in the summer as well as in the winter although the percentage contribution to the total diet is below 10% in all cases. The development of gonads is

usually accomplished at the expense of body proteins which are removed from the muscle and replaced with water (Love, 1970). The proteins and nutrients gained from the digestion of the perch are probably important for both the ripening of the gonadal products and for assisting in the recovery of the fish from the stress of spawning.

The occurrence of large numbers of small fish in the diet of lake whitefish was not reported by Bidgood (1972; 1973), Kennedy (1949), Hart (1931) or Watson (1963) although most authors reported the occasional small fish eaten. McHugh (1939), however, reported sculpins (Cottus sp.) making up an average of 18% of the food organisms found in 37 lake whitefish taken from Okanagan Lake during the summer of 1935. Hart (1931) reported that lake whitefish were being caught during the winter in Lake Simcoe by baiting an area with small fish to attract the whitefish which were later captured on hooks baited with similar food.

The major constituent of the diet of lake whitefish sampled at the WW site between September and May was the small green shoots of the submerged macrophyte Elodea canadensis (Figure 9). Aquatic plants formed only an insignificant (<5%) part of the diet of the fish sampled at the CW site. A review of the literature did not reveal any instances of such a high utilization of aquatic plants by whitefish. Numerous authors (Hart, 1931; Watson, 1963; McHugh, 1939; and Van Oosten and Deason, 1939) have noted

occasional findings of plant material in the stomachs but this is generally attributed to accidental ingestion while feeding on invertebrates.

The amount of nutrients extracted during digestion of the Elodea shoots is not known. However, Hoar and Randall (1969) and Friedman and Shibko (1969) report that many fish can digest certain carbohydrates and derive nutrients (carbohydrates, proteins and lipids) from the cell contents of plants. Analysis of the chemical composition of samples of Elodea canadensis taken from Lake Wabamun is shown in Table 5 (Rick Haag, pers. comm., 1974). Lake whitefish can probably digest some nutrients from the Elodea that they ingest, but it is not expected that they would gain as much from it as they would from animal foods. The fish would also obtain nutrients from any epiphytic fauna and flora that were ingested along with the Elodea.

Many other taxa of invertebrates contributed to a much lesser extent (<5%) to the diet of the whitefish in the lake and are included as miscellaneous in Figure 9. These include Bryozoa, Nematoda, Hirudinea, Ostracoda, Copepoda, Arachnida, Hydracarina, Ephemeroptera, Coleoptera, Odonata, Corixidae, Notonectidae, Chaoborinae, Ceratopogonidae and terrestrial insects. Algae, Chara, macrophyte seeds, wood, sand, and pebbles were also noted in small quantities in stomachs examined.

The stomach analysis data from the sampling period June

Table 5. The chemical composition of *Elodea canadensis* samples taken between November, 1973 and April, 1974. The composition is given in percentage of dry weight. (Data from Rick Haag, pers. comm., 1974).

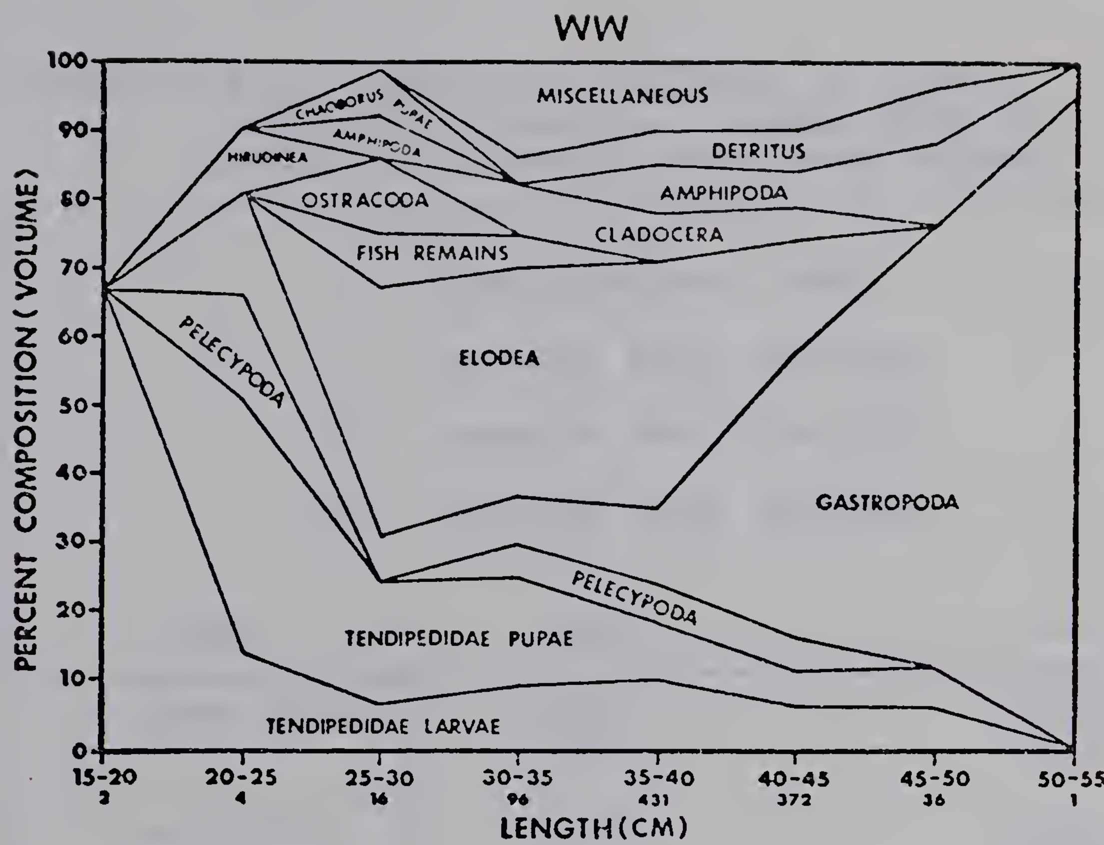
Nitrogen	2.2%
Crude Protein	13.75%
Phosphorus	0.42%
Monosaccharides	1.23%
Oligosaccharides	1.06%
Starch	2.90%
Remainder	78.5%

(The remainder consists to a large extent of crude fiber, but also includes minerals etc. that have not been analysed).

1972 to June 1973 were examined to determine differences in the diet of the whitefish from the two sampling sites for the different sizes of fish (Figure 10). At the CW site, the small fish fed to a larger extent on planktonic organisms (cladocerans, copepods and tendipedid pupae) as well as on aerial insects. The larger fish relied more on benthic invertebrates (tendipedid larvae and pelecypods) as well as on small fish. At the WW sampling site, the whitefish fed on a greater variety of food organisms than at the CW site, with the smaller fish eating predominantly tendipedid larvae and pupae. The medium-sized whitefish (25 cm to 40 cm) fed to a greater extent on Elodea shoots while the larger fish (40 cm to 55 cm) relied more on gastropods. The small sample sizes at the extremes of the size range makes comparisons difficult. The data indicate that the fish in the CW area shift from plankton feeding to bottom and piscivorous feeding as the size of the fish increases. The fish in the WW area on the other hand, do not show this trend, as the small fish feed on a large diversity of organisms, shifting to Elodea shoots predominantly and then to gastropods as the size of the fish increases.

The mean percentage fullness of the lake whitefish stomachs from fish sampled at both the WW and the CW sites were compared using the Wilcoxon's two-sample test to determine if, on the average, the fish sampled at one site had fuller stomachs than at the other site (Table 6). It was found that the fish at the CW site had fuller stomachs

Figure 10. Percentage composition of food items in the diet of lake whitefish in Lake Wabamun according to 5 cm size classes. Data from fish sampled between June, 1972 and June, 1973. Sample sizes are shown below the size class.


WW
PERCENT COMPOSITION (VOLUME)
100
90
80
70
60
50
40
30
20
10
0
MISCELLANEOUS
CHAOBORUS PUPAE
AMPHIPODA
HIRUDINEA
DETRITUS
OSTRACODA
AMPHIPODA
CLADOCERA
FISH REMAINS
ELODEA
PELECYPODA
GASTROPODA
PELECYPODA
TENDIPEDIDAE PUPAE
TENDIPEDIDAE LARVAE
15-20
3
20-25
4
25-30
16
30-35
96
35-40
431
40-45
372
45-50
36
50-55
1
LENGTH (CM)

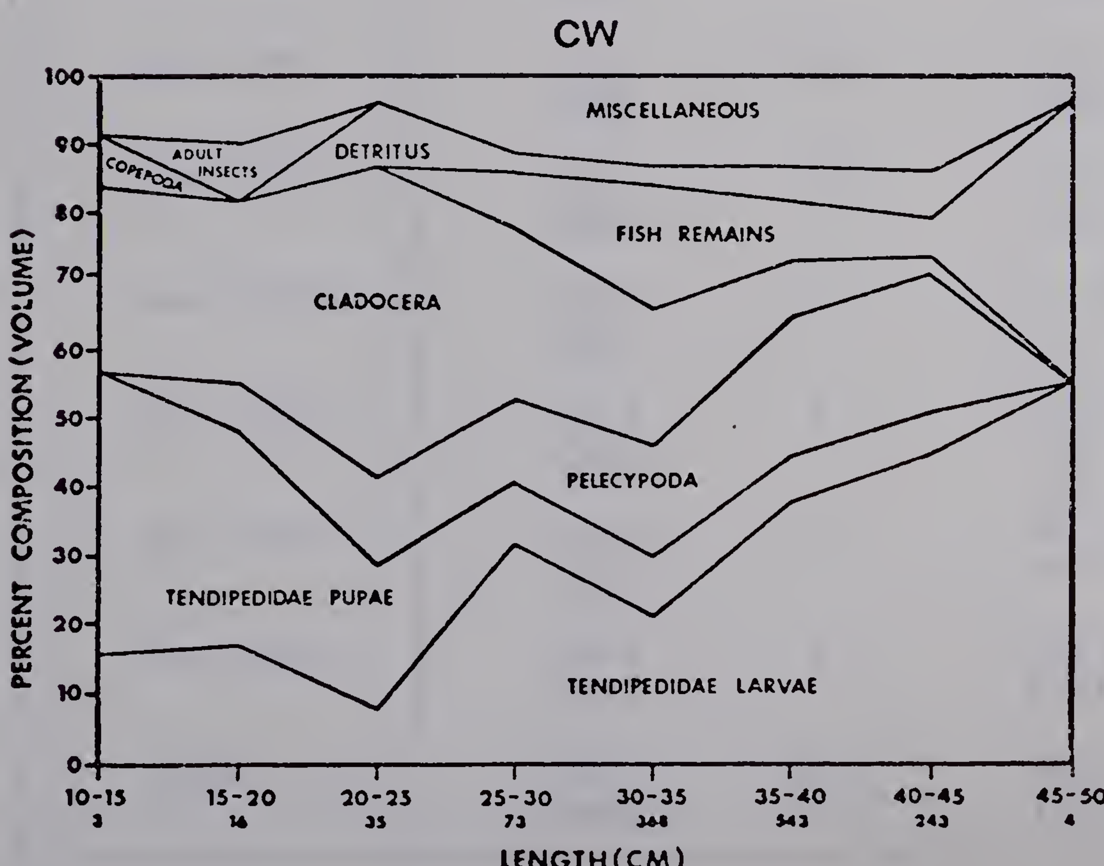

CW
PERCENT COMPOSITION (VOLUME)
100
90
80
70
60
50
40
30
20
10
0
MISCELLANEOUS
ADULT INSECTS
COPEPODA
DETRITUS
FISH REMAINS
CLADOCERA
PELECYPODA
TENDIPEDIDAE PUPAE
TENDIPEDIDAE LARVAE
10-15
3
15-20
16
20-25
35
25-30
73
30-35
368
35-40
543
40-45
243
45-50
4
LENGTH (CM)

Table 6. Mean percentage fullness of lake whitefish stomachs. Sample size is shown in brackets below each value.

= - approximately equal

> - greater than ($p<0.05$)

>> - greater than ($p<0.01$)

>>> - greater than ($p<0.001$)

DATE	WW		CW
June 1972	32.7 (57)	=	28.4 (102)
July 1972	47.5 (80)	=	54.5 (338)
Aug 1972	39.2 (141)	<<<	55.3 (161)
Sept 1972	43.1 (98)	=	38.7 (107)
Oct 1972	8.4 (81)	<<<	58.0 (134)
Nov 1972	2.8 (27)	<<<	31.8 (52)
Dec 1972	30.1 (55)	<<	50.8 (51)
Jan 1973	38.2 (67)	=	42.4 (89)
Feb 1973	43.2 (25)	>	22.4 (25)
Mar 1973	43.6 (64)	>	31.6 (41)
May 1973	68.9 (70)	>	50.9 (28)
June 1973	68.1 (99)	>>>	47.6 (160)

during October and November ($p<0.001$) as well as during December ($p<0.01$) of 1972 than did fish caught at the WW site. Large numbers of small perch were being fed upon by the whitefish at the CW site during this period. A small number of perch will completely fill a whitefish stomach. The mean fullness of the stomachs in the warm water was much lower during the spawning period of October and November than it was during the rest of the year, indicating a reduction in the feeding activity during spawning by fish at the WW site. This is consistent with the observations of Van Oosten and Deason (1939) in Lake Champlain and by Hart (1931) in lakes in Ontario. Thus, the whitefish at the CW site were feeding heavily on the small perch during this time, while the WW fish showed reduced feeding so that the difference in the mean fullness between the two sites was very large.

The fish at the WW site had fuller stomachs during February to May ($p<0.05$) and also during June ($p<0.001$) of 1973 than did the fish at the CW site. This is partially due to the consumption by the WW fish of large amounts of <u>Elodea</u> shoots during this period. Also, cladocerans and tendipedid pupae appeared in the diet earlier in the warmwater samples indicating an increase in the numbers of these organisms earlier in the warmer water than in colder waters.

The standing crop of bottom fauna at the WW site was significantly greater than that at the CW site ($p<0.01$ by

the paired t-test) when compared over a year-long period (Table 7). Tendipedid larvae were the predominant organisms in the samples at both sites. They were considerably more abundant at the WW site than at the CW site, with the exception of June 1973, when large numbers of tendipedid larvae suddenly appeared at the CW site. This was attributed to the fact that large numbers of very small Calopsectrine* larvae appeared at the CW site. These large numbers may be explained by the absence of the large Chironomus plumosus, a species that may out-compete the smaller Calopsectrine larvae (Joe Rasmussen, pers. comm., 1974). Also, Chironomus plumosus may have emerged prior to sampling. The Calopsectrine larvae are utilized very little by the lake whitefish for food. Chironomus spp., however, are an important food item in the diet of the whitefish.

Gallup et al (1973) also reported that the standing crop of zoobenthos was significantly greater in the heated area than in the unheated area. They estimated that the biomass of zoobenthos may be as much as an order of magnitude higher in the heated area due to the common occurrence of large Chironomus sp. which were not common near Fallis in the coldwater area.

Hydracarina were much more numerous in the heated area than at the CW site. This was reflected in the diet of the

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* A tribe of Tendipedidae

Table 7. The standing crop of bottom fauna at the WW site and the CW site. The values given are the mean number per 36 square inches (232 sq cm) based on five samples.

		1972									1973		
	Site	June	Early July	Late July	Early August	Late August	Sept	Oct	Dec	Jan	March	May	June
Tendipedidae	W	118.4	42.4	16.0	20.8	9.4	38.8	64.4	73.5	78.0	68.6	59.0	120.3
	C	32.6	16.6	19.2	13.8	7.4	17.6	29.0	-	28.0	14.6	32.0	147.4
Ceratopogonidae	W	0	0	0	0	0	0	0	0	1.0	0	1.0	0
	C	1.0	0	0	0	0	0	0.3	-	0.3	0.3	2.3	0.3
<u>Chaoborus</u> sp.	W	0	0	0	0	0	0	0.2	2.0	1.0	2.3	0	0
	C	1.2	0.9	0	1.8	0.2	4.0	5.2	-	0.6	0.6	0.3	0.6
Gastropoda	W	0.2	0.8	0	0	0	3.8	2.2	5.5	0	4.2	0.3	0.6
	C	0	0.2	0.2	0	0	0.6	0	-	0	0.8	3.0	0
Pelecypoda	W	0.8	1.2	0	0	0	0	1.8	0	2.3	2.6	2.0	4.0
	C	0	0	0	0	0	0	0	-	0	0	2.0	0.6
Amphipoda	W	0	0.8	0	0.6	0.4	0.8	3.4	0	3.0	1.3	10.3	1.8
	C	0.4	0.6	4.6	4.2	1.4	1.4	2.0	-	6.0	1.3	0.6	0.4
Hydracarina	W	0.8	1.2	0.2	1.6	7.6	3.8	19.2	10.0	24.3	36.3	30.0	6.5
	C	0	0.2	0.4	0.4	1.0	0.2	0.8	-	1.6	1.6	0.6	0
Oligochaeta	W	5.6	21.4	11.2	7.4	5.8	59.0	7.0	60.5	38.0	67.3	55.0	15.0
	C	1.2	1.8	2.8	2.4	1.2	0.6	1.0	-	0.6	1.0	3.3	2.4
Hirudinea	W	0	0	0	0.2	0	0	1.6	0	0.6	1.0	0	0.2
	C	0	0	0.6	0.2	0.8	0.2	0.4	-	0	0	0.3	0
Nematoda	W	0	0	0	0	0	0	0	0	0	0	0	0
	C	0.2	1.4	0	1.0	0.2	0.4	0	-	0	0	0.3	0
<u>Dugesia</u> sp.	W	1.6	0	0.6	2.4	4.4	1.8	1.8	0	2.3	0.6	0	1.5
	C	0	0.2	0	0	0	0	0	-	0	0	2.3	0
Ephemeroptera	W	0	0	0	0	0	0	0	1.0	0	0	0	0
	C	0.2	0	0	0	0	0	0	-	0.3	0.3	0.3	0
Trichoptera	W	0	0	0	0	0	0	0	0	0	0.6	0	0
	C	0	0	0	0	0	0	0	-	0	0	0	0
Totals	W	127.4	68.8	28.0	33.0	27.6	108.0	101.6	152.5	150.5	184.8	153.6	149.9
	C	36.8	26.9	27.8	23.6	12.2	25.0	38.4	-	37.4	20.0	48.6	151.7

whitefish by the greater occurrence of Hydracarina in the stomachs of the fish at the WW site although they only contributed a minor amount (less than 5%) to the total diet. Oligochaetes were also more numerous at the WW site but the whitefish very rarely fed upon them.

Gastropods and trichopterans were important food items in the warm water (Figure 9). The standing crop of both groups was probably greatly underestimated owing to sampling technique since these organisms are usually found attached to aquatic plants which were avoided when the dredge samples were taken.

The standing crop of zooplankton at both the WW and the CW sites showed a distinct spring and autumn pulse (Figure 11). The spring pulse in the warm water was greater than that at the CW site especially with regard to the Cladocera. A smaller autumn pulse occurred in September in the warm water while in the cold water the autumn pulse did not occur until October. This was probably owing to faster reproductive and growth rates in the heated water. The standing crop of cladocerans (mainly <u>Eurycercus</u> sp.) remained higher throughout the winter in the warm water than in the cold water. The number of ephippial eggs eaten by the whitefish at the CW site throughout the winter indicated that conditions in the coldwater areas were not suitable for the adult cladocerans. Copepods, on the other hand, remained more abundant at the CW site throughout the winter.

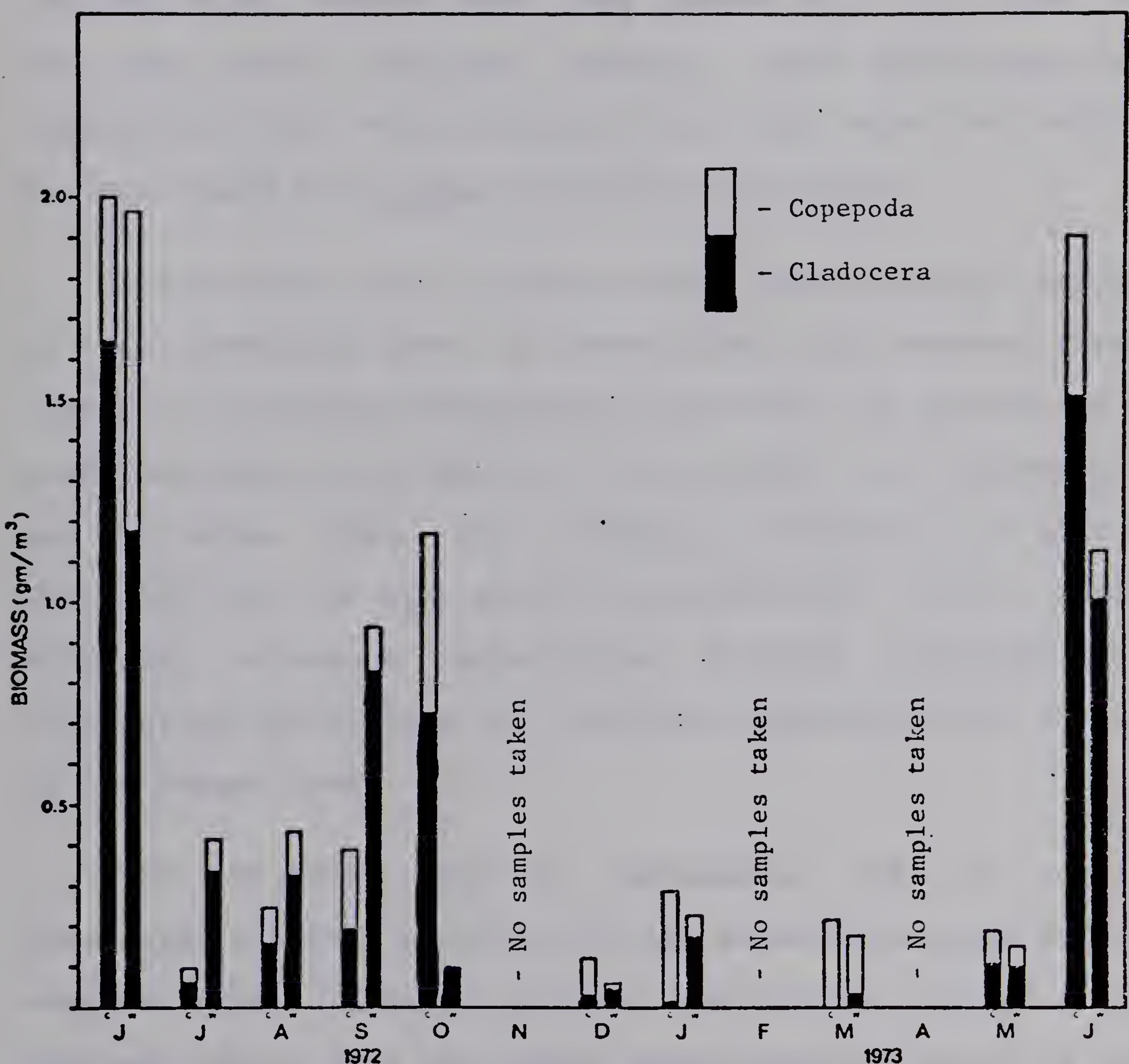


Figure 11. The standing crop of zooplankton of both the warm water (W) and the cold water (C) sampling sites between June, 1972 and June, 1973.

In summary, throughout most of the year, whitefish were opportunistic feeders, eating the most abundant or most available food. During the spawning period, the whitefish in the warm water reduced their food intake while the fish in the cold water continued feeding, small perch being the predominant food. The whitefish in the warm water fed mainly on small shoots of Elodea throughout the winter.

The standing crop of bottom fauna was generally larger in the warmwater area. The heated area also harbours large numbers of submerged macrophytes with which are associated a large diversity of organisms, many of which are included in the whitefish diet. The decaying macrophytes are also a source of food for many benthic invertebrates. This, along with the increased temperatures probably increases the invertebrate production and therefore whitefish food supply in the heated area.

The standing crop of zooplankton did not remain consistently higher at either of the sites during the period studied. The standing crop of zooplankton showed two distinct pulses with the autumn pulse occurring later in the coldwater area. Cladocerans remained in higher numbers in the warm water during the winter. Copepods, on the other hand, were present in large numbers in the cold water throughout most of the winter. The cladocerans are an important source of food for the whitefish while the copepods are eaten very rarely by the adult fish, although

they are probably very important for the young-of-the-year whitefish.

B. Condition Factors, Length-Weight Relationships and Growth

Since there are differences in the quality and quantity of food eaten by the whitefish, it was thought that the differences might be reflected in the fatness or condition of the fish. The condition factor (K) was calculated by the following formula:

$$K = \frac{100W}{L^3} \quad \text{(Hile, 1936)}$$

where W=total weight of the fish in grams and L=fork length in centimeters. The condition factor was used as an index of the fatness or general well-being of the fish. The mean condition factor for fish captured at the two sampling sites is compared in Table 8. The mean value of K was not significantly different during August 1972 or between October 1972 to March 1973 ($p=0.05$). The K value at the WW site was greater than the value at the CW site during June 1972 and during May and June of 1973, indicating that the whitefish were starting to feed more and put on weight earlier in the warmwater than in the coldwater area. However, since the value of K at the CW site was significantly greater during July 1972 ($p<0.01$) than at the WW site, and since the two were not significantly different during August, the fish at the CW site catch up in condition to the fish in the warm water.

Table 8. Mean Condition Factor (K). Sample size is shown in brackets below each value.

= - approximately equal

> - greater than ($p<0.05$)

>> - greater than ($p<0.01$)

>>> - greater than ($p<0.001$)

MONTH	MEAN WARM WATER SITE		MEAN COLD WATER SITE
June, 1972	1.3658 (69)	>>	1.3024 (132)
July, 1972	1.4041 (234)	<<	1.4287 (517)
Aug, 1972	1.3850 (146)	=	1.3992 (179)
Sept, 1972	1.4078 (71)	>>	1.3589 (120)
Oct, 1972	1.3917 (10)	=	1.4057 (105)
Dec, 1972	1.3492 (56)	=	1.3667 (45)
Jan, 1973	1.3900 (67)	=	1.3510 (35)
Feb 1973	1.3540 (15)	=	1.3062 (10)
Mar, 1973	1.3045 (41)	=	1.3428 (36)
May, 1973	1.3384 (42)	>>	1.2772 (43)
June, 1973	1.4393 (190)	>>	1.4016 (239)

The value of K depends on the weight of the fish, and therefore, the weight of the developing gonads influences the K value. Since the weight of the female gonads is generally greater than the weight of the male gonads, a disproportionate number of fish of one sex in either of the samples would affect the value of K. Table 9 compares the mean condition factors according to the sex of the fish. The value of K for female fish was larger in the warm water during June and September 1972 ($p<0.01$) and during May and June 1973 but did not differ significantly from the CW samples during the remainder of the year ($p=0.05$). The mean K value of the males in the CW was significantly greater during July and August ($p<0.05$) but significantly less during June and January ($p<0.05$). No consistent relationship between differences in the fullness of the stomachs and significant differences in the condition factors could be found. However, the mean condition factor of the sexes combined for June 1973 was significantly greater at both sites than that for June 1972 ($p<0.01$) at the same sites (Table 10). This corresponds to a greater fullness of the stomachs during June of 1973 compared to June of 1972 at both sites (Table 6).

The slopes of the regression line relating the weight to the length of the fish at the two sites did not differ significantly during most of the year (Table 11). The slope of the regression line for May 1973 in the warm water was

Table 9. Mean condition factor (K) according to sex. Sample size is shown in brackets below each value.

= - approximately equal

\> - greater than ($p<0.05$)

\>> - greater than ($p<0.01$)

\>>> - greater than ($p<0.001$)

MONTH	MALES WW		MALES CW	FEMALES WW		FEMALES CW
June 1972	1.3739 (29)	>	1.3075 (58)	1.3598 (40)	>>	1.2859 (53)
July 1972	1.3885 (73)	<	1.4245 (240)	1.4133 (154)	=	1.4297 (208)
Aug 1972	1.3617 (58)	<	1.4001 (94)	1.4027 (85)	=	1.4074 (81)
Sept 1972	1.3866 (28)	=	1.3522 (50)	1.4216 (43)	>>	1.3660 (69)
Oct 1972	1.3973 (9)	=	1.4179 (47)	1.3414 (1)	=	1.3960 (58)
Dec 1972	1.3568 (31)	=	1.3950 (19)	1.3398 (25)	=	1.3461 (26)
Jan 1973	1.3995 (24)	>	1.2877 (5)	1.3847 (42)	=	1.3615 (29)
Feb 1973	1.3351 (6)	=	1.3244 (7)	1.3666 (9)	=	1.2636 (3)
Mar 1973	1.3753 (8)	=	1.3869 (6)	1.2874 (33)	=	1.3340 (30)
May 1973	1.3352 (6)	=	1.3117 (6)	1.3389 (36)	>>	1.2716 (37)
June 1973	1.4185 (72)	=	1.4092 (128)	1.4520 (118)	>>	1.4092 (101)

Table 10. Comparison of condition factors from June, 1972 and June, 1973. The sample size is shown in brackets below each value.

= - approximately equal

> - greater than (p<0.05)

>> - greater than (p<0.01)

>>> - greater than (p<0.001)

DATE	WW SITE		CW SITE
June 1972	1.3658 (69)	>>	1.3024 (132)
	∧∧		∧∧
June 1973	1.4393 (190)	>>	1.4016 (239)

CONDITION FACTOR OF MALES

June 1972	1.3739 (29)	>	1.3075 (58)
	=		∧∧
June 1973	1.4185 (72)	=	1.4092 (128)

CONDITION FACTOR OF FEMALES

June 1972	1.3598 (40)	>>	1.2859 (53)
	∧∧		∧∧
June 1973	1.4520 (118)	>>	1.4092 (101)

Table 11. Length-Weight Relationships. Months with small sample sizes (<30) at either of the sites are deleted. (*) indicates the slopes differ significantly ($p<0.05$).

MONTH	SITE	EQUATION	n
June 1972	WW	$W=0.0301L^{2.784}$	69
	CW	$W=0.0154L^{2.951}$	132
July 1972	WW	$W=0.0151L^{2.978}$	234
	CW	$W=0.0171L^{2.950}$	517
Aug 1972	WW	$W=0.0184L^{2.921}$	146
	CW	$W=0.0121L^{3.039}$	179
Sept 1972	WW	$W=0.0081L^{3.150}$	71
	CW	$W=0.0109L^{3.060}$	120
Dec 1972	WW	$W=0.0570L^{2.608}$	56
	CW	$W=0.0441L^{2.670}$	45
Jan 1973	WW	$W=0.0372L^{2.730}$	67
	CW	$W=0.0620L^{2.579}$	35
March 1973	WW	$W=0.0137L^{2.986}$	41
	CW	$W=0.0190L^{2.903}$	36
May 1973	WW	$W=0.0032L^{3.389}$ *	42
	CW	$W=0.02a0L^{2.863}$	43
June 1973	WW	$W=0.0226L^{2.877}$ *	190
	CW	$W=0.0100L^{3.092}$	239

significantly greater than at the coldwater site ($p<0.05$) but was significantly less during June 1973 ($p<0.05$). Since the slopes of the regression lines were not significantly different for most of the year and since any significant differences were not consistently found at any one site, it was concluded that the heated water did not affect the length-weight relationship.

The length-to-age and weight-to-age relationships for lake whitefish of age one to four years obtained from combined samples taken at both sites in July 1972 are shown in Figure 12. It was felt that only the younger fish (up to 4 years old in samples taken before May, 1973 and up to 5 years old after that) could be aged accurately so only data for fish up to 4 years old are shown in Figure 12. Unfortunately, it was not possible to compare mean lengths or weights for each age class from the two sampling sites for the following reasons: 1) age determination for the older fish was not possible; and 2) sample sizes of the younger fish were often small.

The data from this study showed that most female lake whitefish did not spawn until they were five years of age although some spawned at age four and a small percentage did not spawn until they were six years old (Table 12). The majority of the males spawned at four years of age and all were mature at five years of age. No mature or ripe three year old lake whitefish were captured. The age of maturity

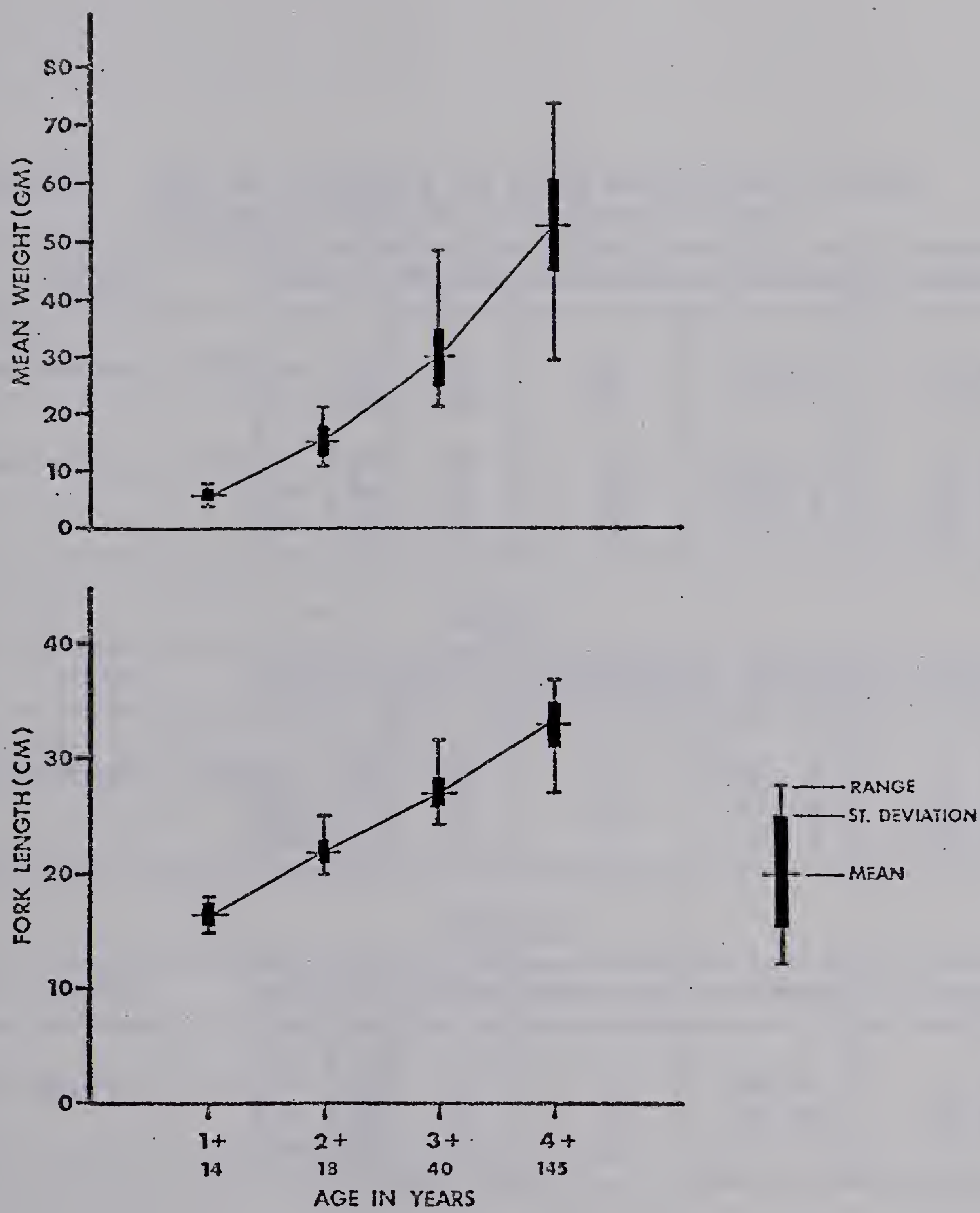


Figure 12. Length and weight of age 1+ to 4+ lake whitefish, July, 1972. Data are from both the WW and the CW sites. Sample sizes are shown below the age.

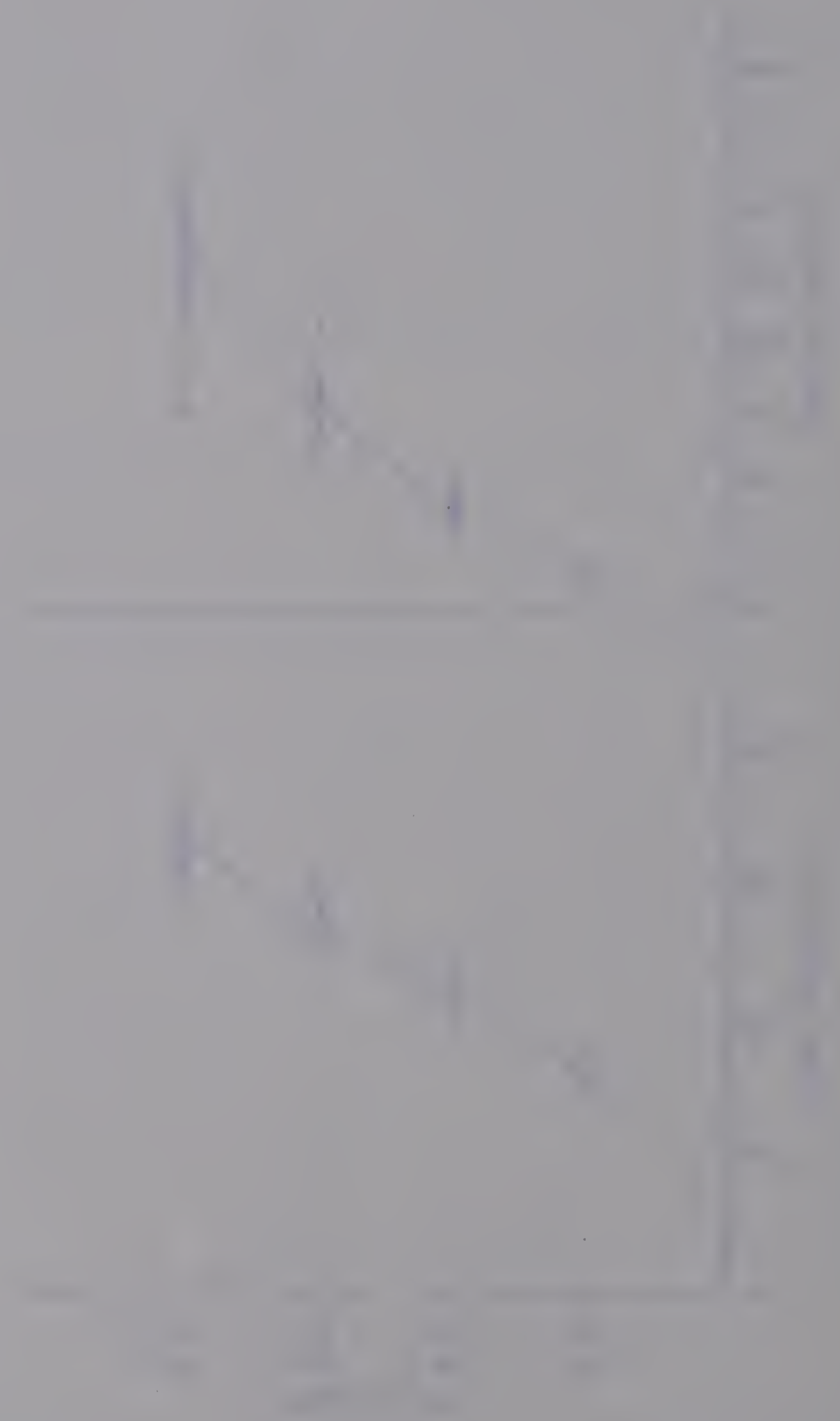


Table 12. Age of Maturity of Lake Whitefish in Lake Wabamun, 1972-73. (N=sample size)

DATE	AGE	N	MATURE	IMMATURE	% MATURE	% IMMATURE
September, 1972	4+	40	17	23	42.5%	57.5%
	3+	12	0	12	0 %	100 %
September, 1973	5+	57	54	3	94.7%	5.3%
	4+	16	8	8	50 %	50 %
	3+	2	0	2	0 %	100 %

MALES

DATE	AGE	N	MATURE	IMMATURE	% MATURE	% IMMATURE
September, 1973	5+	24	24	0	100 %	0 %
	4+	7	5	2	71.4%	28.6%
	3+	1	0	1	0 %	100 %

FEMALES

DATE	AGE	N	MATURE	IMMATURE	% MATURE	% IMMATURE
September, 1973	5+	33	30	3	90.9%	9.1%
	4+	9	3	6	33.3%	66.7%
	3+	0	0	0	-	-

of lake whitefish in Lake Wabamun is one year greater than that found by Bidgood (1972; 1973) for lake whitefish in Pigeon and Buck lakes and by Hart (1930) and Budd and Cucin (1962) for whitefish in Lake Ontario and and Lake Huron respectively. It was however, less than the age of maturity (8 years of age) reported by Qadri (1968) in Lac la Ronge, Saskatchewan. In the present study it was found that a larger percentage of males than females spawned at four years of age. This is consistent with the findings of Van Oosten (1939), Van Oosten and Hile (1949), and Cucin and Regier (1966), but is contrary to the findings of Kennedy (1953) and Bidgood (1972; 1973).

It was thought that differences in the quality and quantity of food and differences in the metabolic rate due to temperature differences at the two sites might affect the rate of maturation of the gonadal products of the fish. To test this hypothesis, the gonadosomatic index (GSI) was calculated for female fish from the formula (Smiley, 1972)

$$GSI = \frac{\text{Total weight of both ovaries X 100}}{\text{Total weight of the fish}}$$

The means from both sites were compared statistically. However, for the comparisons of the GSI to be meaningful, the GSI must remain fairly constant as the size of the fish increases. To determine if this was the case, the log of the GSI for each fish was plotted against the total weight of the fish. An example of such a plot (for lake whitefish caught in June 1972 at the WW site) is shown in Figure 13.

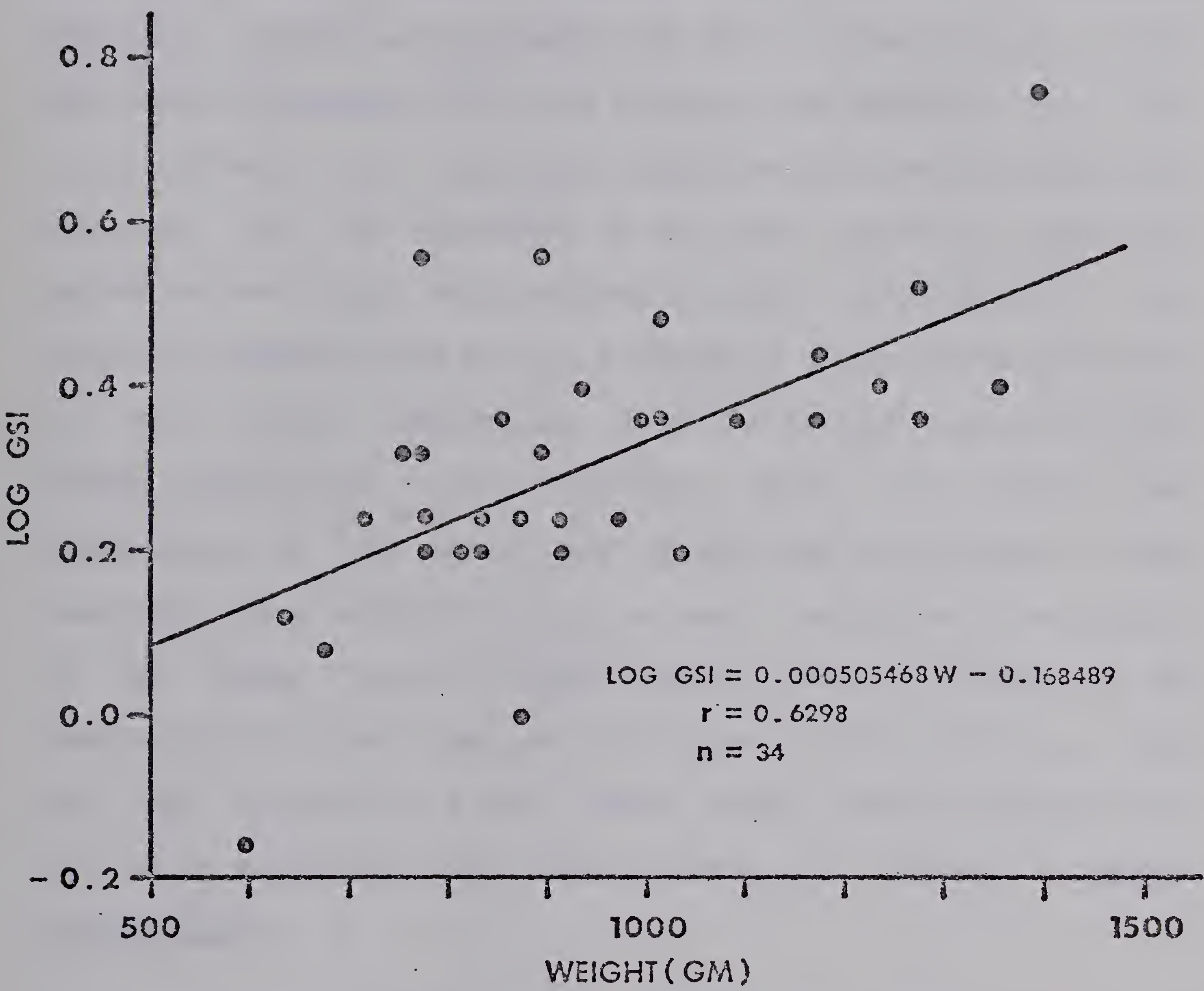


Figure 13. Log gonadosomatic index (GSI) versus weight for lake whitefish from June, 1972 at the WW site. Notice the very small slope of the regression equation.

The regression coefficients were determined for the samples for each month at each site (Table 13). The slope of the regression line did not differ significantly from zero ($p=0.05$) for the months December 1972 and for January, February, March and September of 1973 at the WW site or for the months December 1972, and January and February of 1973 at the CW site. The slope did differ significantly from zero ($p<0.05$) for the remainder of the data. However, since the values of the slope were extremely small (<0.0008517), the effect of larger fish having a slightly greater GSI would be of very little importance over the narrow ranges of body weight encountered and therefore, would not affect the comparison of the mean GSI from the two sites. It was concluded that although there is some individual variation in the gonad weight to body weight ratio, it tended to be constant at any one time for all sizes of fish of the same sex and maturity. Le Cren (1951) found similar results for the ovary weight to body weight ratio for perch (*Perca fluviatilis*).

The mean GSI of samples of lake whitefish from the WW site was significantly greater ($p<0.01$) than for samples taken from the CW site during June and September 1972 and March, May, June and September 1973 (Table 14; Figure 14). It was also greater during August of 1972 ($p<0.05$). During the remainder of the period studied, the mean GSI of both samples were not statistically different. The data in Table 14 show that after spawning, the fish in the warmwater area

Table 13. Slope of regression of log GSI versus body weight. The significance level is shown when the slope is significantly different from zero. The sample size is shown in brackets below.

MONTH	WW		CW	
July, 1972	0.000505 (36)	0.001	0.008517 (35)	0.001
July, 1972	0.0005155 (80)	0.0001	0.0003551 (60)	0.0001
Aug, 1972	0.0003370 (64)	0.0001	0.0002951 (52)	0.05
Sept, 1972	0.0000961 (38)	0.05	0.0002952 (42)	0.01
Oct, 1972	- (0)		0.0012348 (23)	0.05
Dec, 1972	0.0000596 (22)		0.0001852 (8)	
Jan, 1973	0.0000404 (36)		0.0003055 (22)	
Feb, 1973	0.0000509 (9)		-0.00000255 (3)	
March, 1973	0.0002262 (28)		0.0003480 (19)	0.05
May, 1973	0.0002728 (36)	0.05	0.0002647 (34)	0.05
June 1973	0.0003148 (55)	0.001	0.0002962 (36)	0.01
Sept, 1973	0.0000345 (44)		0.0002084 (39)	0.01

Table 14. Mean gonad weight/body weight ratio (GSI) of lake whitefish from the two sites. Sample size is shown in brackets below each value.

= - approximately equal
> - greater than ($p<0.05$)
>> - greater than ($p<0.01$)
>>> - greater than ($p<0.001$)

DATE	WW		CW
June, 1972	2.1716 (36)	>>	1.3489 (35)
Early July, 1972	2.6610 (52)	=	2.3939 (28)
Late July, 1972	3.2501 (28)	=	3.1276 (38)
Early Aug, 1972	4.5863 (34)	=	4.1620 (34)
Late Aug, 1972	5.2977 (30)	>	4.6669 (18)
Sept, 1972	8.2949 (38)	>>	7.2144 (42)
Oct, 1972	- (0)		6.6066 (23)
Dec, 1972	1.2141 (22)	=	1.2265 (8)
Jan, 1973	0.8891 (36)	=	0.9903 (22)
Feb, 1973	0.8470 (9)	=	0.9506 (3)
March, 1973	1.1043 (28)	>>	0.8665 (19)
May 1973	1.4059 (36)	>>	1.0604 (34)
June, 1973	2.3721 (55)	>>	1.8690 (39)
Sept, 1973	12.3214 (44)	>>	10.4328 (39)

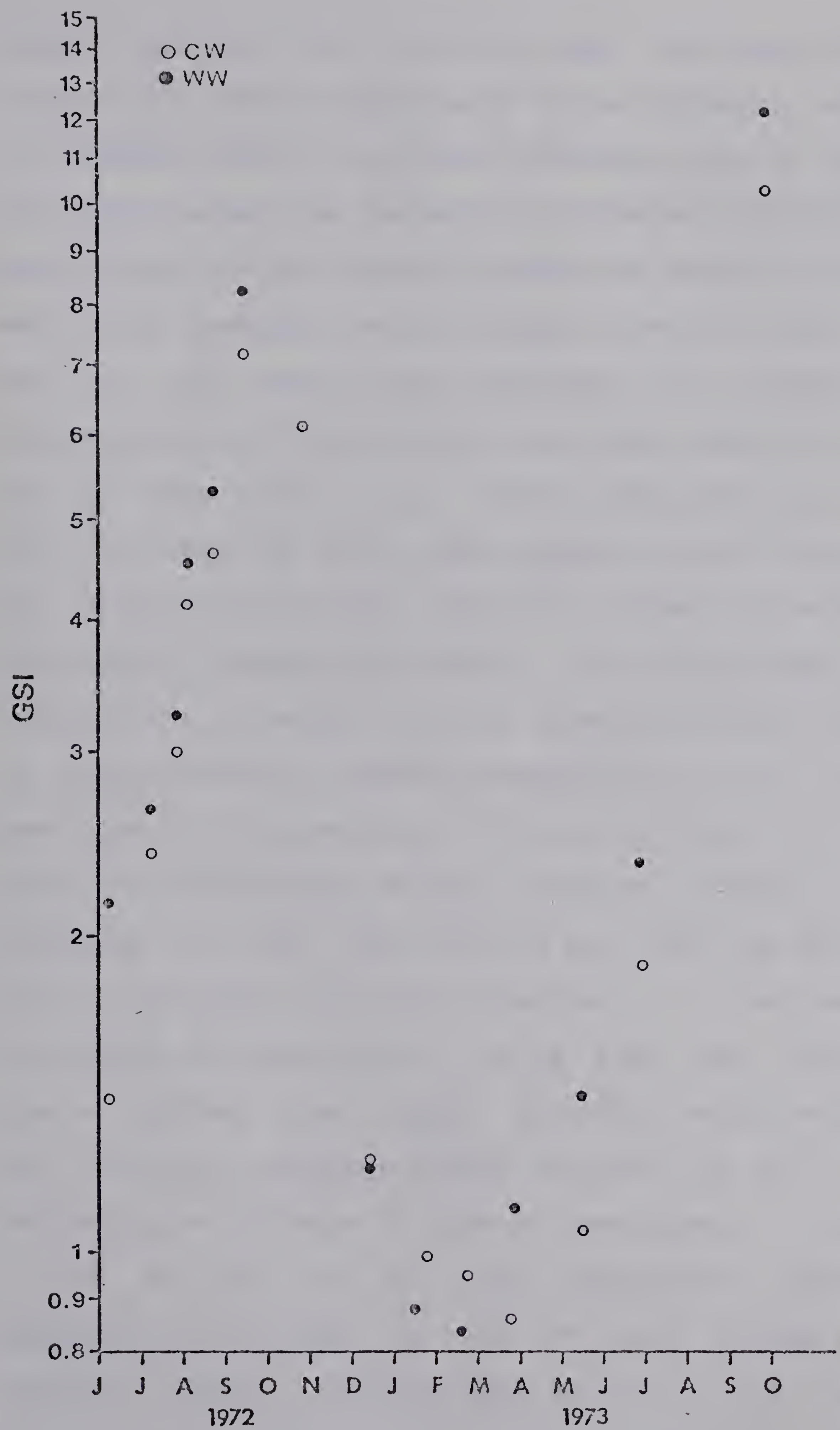


Figure 14. Mean GSI (gonad weight X 100/total body weight) of female lake whitefish from both the warmwater site (WW) and the coldwater site (CW).

began resorbing the residual eggs and connective tissue earlier than their counterparts in the coldwater area. This is probably due to the higher metabolic rate of the fish in the heated water. The warmwater fish began production of the new ovarian tissue in March whereas the fish at the CW site were still resorbing their residual tissue at this time. The fish in the heated areas therefore, got a 'head start' in the production of new ovarian tissue and remained ahead of the CW fish until June. During July and early August of 1972, the mean GSI of the fish sampled at the two sites did not differ statistically ($p=0.05$) although the value itself was greater. During this period , the development of the ovary in the WW sample may have slowed, allowing the CW fish to nearly catch up. Another possibility is that the rate of development of the ovaries of the CW fish may have increased while the rate for the WW fish remained constant. Also, a migration of fish from the CW area into the WW area just prior to sampling would have resulted in a lower mean GSI of the sample. The mean GSI of the WW fish was statistically greater during late August ($p<0.05$), during September of 1972 ($p<0.01$), and again during September of 1973 ($p<0.01$), indicating an increase in rate of development of the ovaries at the WW site as the fish approached spawning. This suggests that the fish at the WW site probably spawned slightly earlier, although this was not proved. The samples of fish for September, 1973 were taken later in the month than those of 1972 and therefore the ovaries were further

developed, resulting in a larger value of GSI (Table 15). The weight of the ovaries in September 1973 at the WW site accounted for an average of 12.32% of the total weight of the fish. The mean GSI for fish sampled in October of 1972 had dropped indicating that a portion of the sample had already spawned.

The first ripe whitefish was taken on October 3, 1972 when the water temperature ranged from 9.0° C at the surface to 8.6° C at the bottom. The last ripe female was taken on December 12, 1972. Samples of fish obtained on the spawning beds on October 4, 1973, contained no ripe fish indicating that spawning had not yet begun. The water temperature at this time ranged from 11.3° C at the surface to 11.2° C at the bottom. On October 18, 1973, the first ripe female whitefish was captured and the first whitefish egg was picked up in an Ekman dredge sample. The water temperature ranged from 7.6° C at the surface to 7.5° C at the bottom. Ripe male whitefish were taken on October 10, 1973 at both the WW and the CW sites. This indicates that male whitefish were ready to spawn before the females. The temperatures ranged from 15.6 to 9.6° C from top to bottom at the WW site and from 9.0 to 9.1° C at the CW site. Large concentrations of ripe fish were taken on November 15, 1973 under the ice at Fallis Point. This was the last sample taken so the extent of the spawning period was not determined for 1973. Spawning in Lake Wabamun therefore, occurred both before and after ice cover, beginning in early October (October 3, 1972

Table 15. Mean GSI of fish sampled in September of 1972 compared to fish sampled in September of 1973. The sample size is shown in brackets below each value.

= - approximately equal

> - greater than ($p<0.05$)

>> - greater than ($p<0.01$)

>>> - greater than ($p<0.001$)

DATE	WW		CW
September 12 & 13, 1972	8.2949 (38)	>>	7.2144 (42)
	^^		^^
September 25 & 27, 1973	12.3214 (44)	>>	10.4328 (39)

and October 18, 1973) when the surface water temperature was 9.0 in 1972 and 7.6 in 1973, and continuing until early December when the water temperature was near 1° C. Hart (1930) reported that whitefish began spawning in Lake Ontario in water that ranged from 4.5° to 10° C during 1922 to 1929. Qadri (1968) reported the whitefish spawning period as lasting from the third or fourth week in October to mid-November in Lac la Ronge, Saskatchewan. Bidgood (1972) reported lake whitefish spawning from late September to late January and from late September to late December for Pigeon and Buck lakes respectively at temperatures ranging from 9.2° C to 1° C.

Poor food supply can lead to atrophy of the oocytes and hence, reduced fecundity (Scott, 1962) and it was thought that since the standing crop of bottom fauna was less at the CW site than at the WW site, the corresponding fecundity might be less also. However, the regression equations relating fecundity to weight at both the WW and CW sites did not differ statistically ($p=0.05$) (Figure 15). This is also true of the regression equations relating fecundity to length (Figure 16). The average fecundity of Lake Wabamun whitefish is 25,600 eggs per kg of body weight of the fish. This figure compares quite closely with the figure of 27,670 given by Bidgood (1972) for Buck Lake, Alberta and the range of 24,250 to 26,455 eggs per kg reported by Milner (1874) for lake whitefish in the Great Lakes. It is however, well above the figure of 18,010 eggs per kg of body weight

Figure 15. Fecundity to weight relationship for lake whitefish taken at both the WW and CW sites during September, 1973. The regression equations are:

a) WW site $\quad \text{Fecundity} = 13.9294\ W^{1.09}$

$r = 0.76$

$n = 47$

b) CW site $\quad \text{Fecundity} = 7.5713\ W^{1.18}$

$r = 0.82$

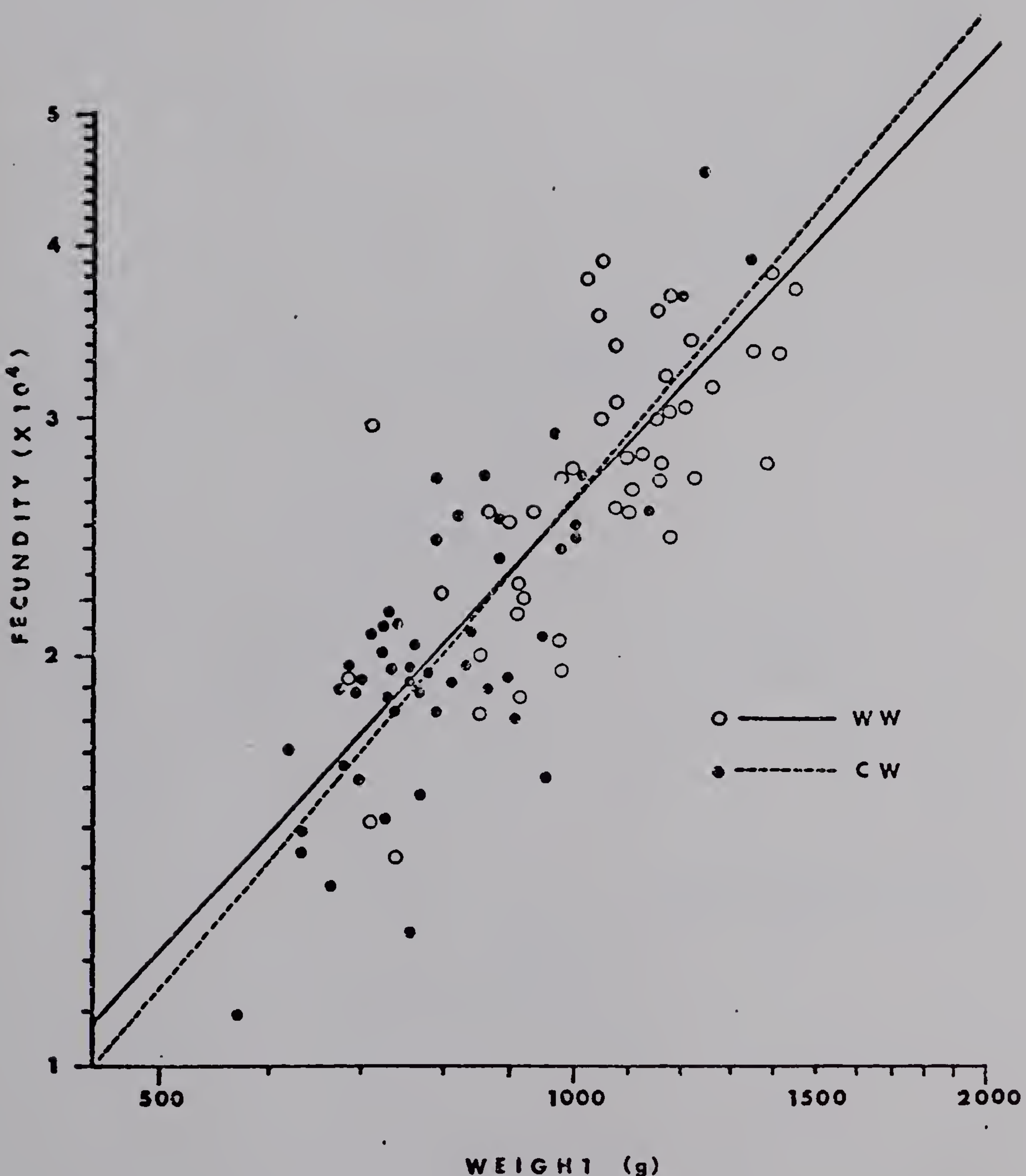
$n = 51$

where weight (W) is given in grams. Neither the slopes nor the intercepts of these regression equations differ statistically ($P<0.05$) and therefore they are both estimates of the same line. The regression equation of both samples pooled together is:

$$\text{Fecundity} = 13.47\ W^{1.09}$$

$$r = 0.84$$

$$n = 98$$



FECUNDITY (X 10⁴)
5
4
3
2
1
500
1000
1500
2000
WEIGHT (g)
WW
CW

Figure 16. Fecundity to length relationship for lake whitefish taken at both the WW and CW sites during September, 1973. The regression equations are:

a) WW site Fecundity = $0.1646\ L^{3.23}$

$r = 0.76$

$n = 47$

b) CW site Fecundity = $0.4700\ L^{2.94}$

$r = 0.74$

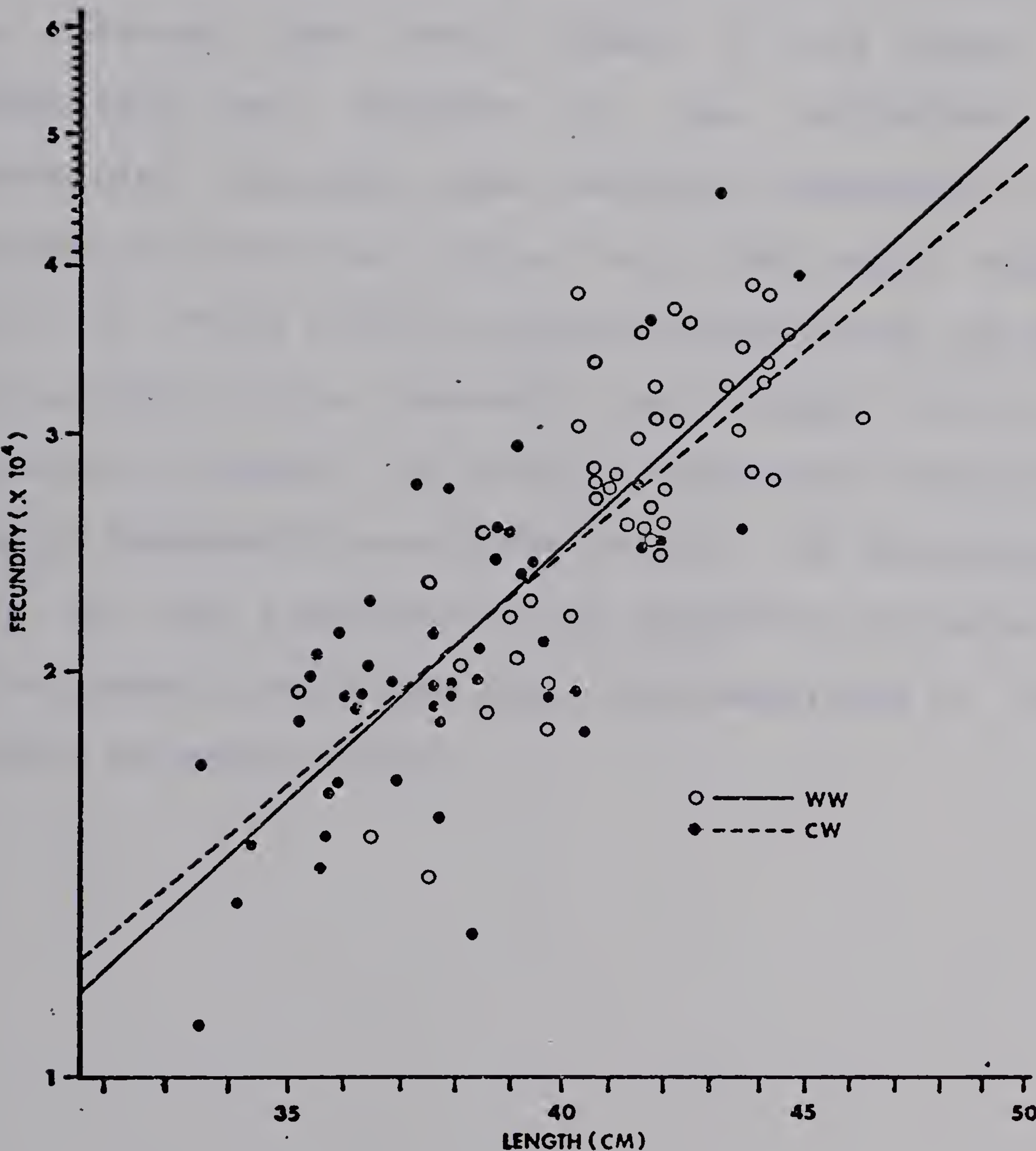
$n = 51$

where the length (L) is given in cm. Neither the slopes nor the intercepts of these regression equations differ statistically ($P<0.05$) and therefore are both estimates of of the same line. The regression equation of both samples pooled together is:

Fecundity = $0.2516\ L^{3.17}$

$r = 0.81$

$n = 98$



FECUNDITY (X 10⁴)
1
2
3
4
5
6
35
40
45
50
LENGTH (CM)
WW
CW

reported for the slow growing whitefish in Pigeon Lake (Bidgood, 1972) and the range of 15,740 to 19,840 given by Qadri (1868) from whitefish in Lac la Ronge, Saskatchewan.

The true fecundity of a sample of five lake whitefish was obtained from total counts of the eggs. The true fecundities were compared to the estimates of the fecundities obtained from weighed subsamples to give an estimate of the error (Table 16). The error ranged from 15.1% to 39.8% with the average being 21.9%. In all cases, the estimate of the fecundity was higher than the true fecundity, because of bits of connective tissue and blood vessels included in the ovary weight. No corrections were made to the estimates of the fecundity to correct for the error since it would not allow the comparison of this data to that of other authors.

Table 16. Error determination for fecundity calculations.

SAMPLE NUMBER	1	2	3	4	5
Length (cm)	35.4	36.4	38.5	41.9	40.5
Weight (g) 12	707.3	730.0	865.8	1200.6	1146.9
Ovary weight (g)	86.1	92.6	121.9	135.7	153.2
True fecundity	15,946	20,286	19,251	17,903	24,175
Subsample(SS) 1wt(g)	1.042	1.1021	1.1933	1.179	1.167
No. eggs in SS1	233	294	219	210	212
Est. 1 Fecundity	19,252	24,702	22,372	24,170	27,831
Error of Estimate 1	20.7%	21.9%	16.2%	35.0%	15.1%
Subsample 2 wt (g)	1.0180	1.0101	1.0032	1.101	1.169
No. eggs in SS 2	231	258	183	203	213
Est. 2 of Fecundity	19,537	23,652	22,236	25,020	27,914
Error of Est. 2	22.5%	16.6%	15.5%	39.8%	15.5%

Average error = 21.9%

Range = 15.1 - 39.8%

3. Reproduction

a) Potential Spawning Areas

Since lake whitefish eggs require low temperatures for successful incubation (Price, 1940), eggs spawned in the areas affected by the heated water discharge may show reduced survival. Hart (1930), Bajkov (1930a) and Bidgood (1972) have shown that whitefish generally spawn on shallow rocky shoals, although some spawn on a sand substrate. Bidgood (1972) pointed out that whitefish eggs in crevices between rocks would be more protected and therefore less vulnerable to predation by fish than would eggs spawned on a flat sand substrate. An analysis of the substrate type of Lake Wabamun (Figure 17) showed that 48.3% of the suitable spawning substrate (rock and sand or sand) was located in the east end of the lake (Figure 6), the portion affected by the heated discharges. The eastern portion of the lake contained 72.6% of the total rock and sand substrate which is the most suitable for spawning and only 22.5% of the less valuable sand (without rocks) substrate (Table 17). The total area of rock and sand substrate was 5.85 km^2 (2.26 mi^2) and the area of sand substrate was 5.54 km^2 (2.14 mi^2) giving a total area in the lake suitable for spawning of 11.4 km^2 (4.4 mi^2).

The largest area with a rock and sand substrate is located along the Indian Reserve on the east side of Indian Bay. This represents 65.2% of the total rock and sand

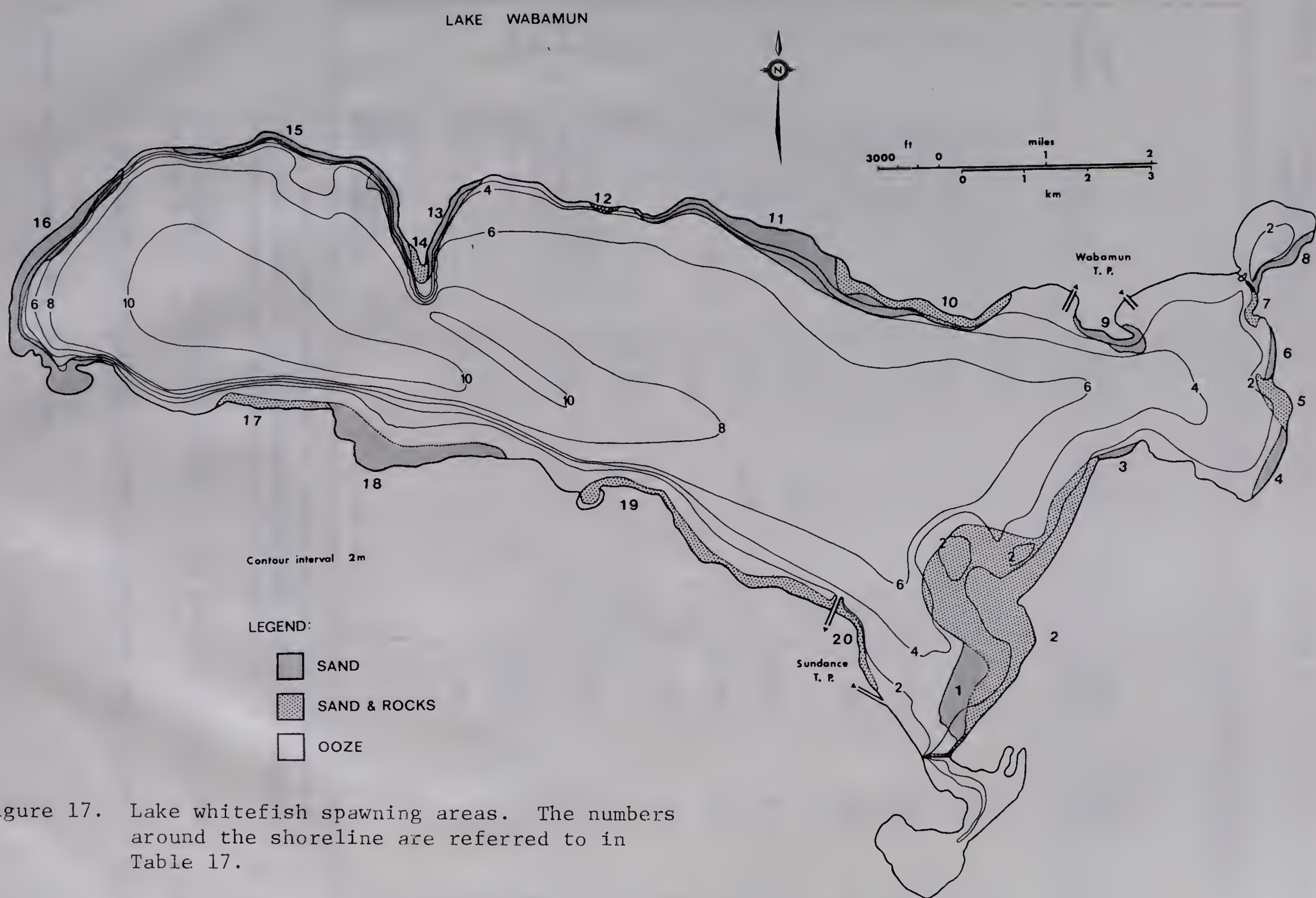


Figure 17. Lake whitefish spawning areas. The numbers around the shoreline are referred to in Table 17.

Table 17. Breakdown of areas suitable for spawning as to location and substrate type.

		SAND			SAND AND ROCK		
MAP* NUMBER	LOCATION	AREA (km^2)	% OF TOTAL SAND	% OF TOTAL	AREA (km^2)	% TOTAL SAND + ROCK	% OF TOTAL
1	Indian Bay	0.546	9.9	4.8			
2	Indian Reserve				3.807	65.2	33.4
3	Indian Reserve	0.062	1.1	0.6			
4	Kapasiwin	0.187	3.4	1.6			
5	Kapasiwin				0.218	3.7	1.9
6	Kapasiwin	0.078	1.4	0.7			
7	Kapawiwin				0.062	1.1	0.6
8	Moonlight Bay	0.156	2.8	1.4			
9	Pt. Allison	0.218	3.9	1.9			
10	Ascot Beach				0.531	9.1	4.7
11	Ascot Beach	1.326	23.9	11.7			
12	Whitewood Sands				0.047	0.8	0.4
13	Fallis	0.240	4.5	2.2			
14	Fallis				0.101	1.7	0.9
15	Fallis	0.671	12.1	5.9			
16	Seba	1.123	20.3	9.9			
17	Betula Beach				0.234	4.0	2.1
18	Rosewood Beach	0.921	16.6	8.1			
19	Sundance				0.687	11.7	6.0
20	Sundance				0.156	2.7	1.4
	TOTAL	5.54			5.84		
	TOTAL AVAILABLE FOR SPAWNING		11.38 km^2				

% of total area suitable for spawning in the east end of the lake (east of a line drawn between the inlet canals of the Wabamun and Sundance outlet canals) = 48.3%

% of primary spawning grounds in the east end (sand and rocks) = 72.6%

% of secondary spawning grounds in the east end (sand) = 22.5%

* Refer to Figure 17 for location.

substrate and so is the most important potential spawning area. Large numbers of ripe female whitefish were captured in gill nets over this area during the spawning periods of both 1972 and 1973. Whitefish were also observed during this period splashing at the surface during the evenings. Such activity indicates that spawning likely was taking place (Bajkov, 1930b).

During the spawning season large numbers of ripe lake whitefish were also captured in gill nets set in heated areas out from the discharge canals of both power plants. The bottom substrate in these areas was a fine ooze. Dredge samples contained large numbers of whitefish eggs (Table 18) indicating that the whitefish had spawned in these areas.

The open water area near the Sundance power plant was utilized quite heavily for spawning. Whitefish eggs occurred in 48% of the 31 dredge samples taken in this area (Table 18) resulting in an average of seven eggs occurring per Ekman dredge sample (232 cm^2 or 36 in^2). The area of the ice free region sampled was approximately 0.78 km^2 (0.3 mi^2) so an average of seven eggs per 232 cm^2 (36 in^2) represented a total of 2.2×10^8 eggs spawned in this area. Using 25,000 eggs as an average value of the fecundity for each fish,the total number of females that had spawned in the area would have been approximately 8,800. However, since eggs were also found on an ooze substrate under the ice in the south-east portion of Indian Bay, this figure probably underestimates

Table 18. Summary of data obtained by dredging for whitefish eggs. From October 1972 to January 1974. All samples with the exception of Oct. and Nov. of 1972 were taken after freeze-up. 'Open area' refers to the area kept ice-free by the heated discharges from the power plants.

DATE	LOCATION	#OF DREDGE SAMPLES	#EGGS	#EGGS PER SAMPLE	% OF SAMPLES CONTAINING EGGS
Oct 30/72	Wabamun Thermal Plume	5	7	1.4	60%
Nov 15/72	Wabamun Thermal Plume	9	7	0.8	11%
Nov 15+24/73	Wabamun Open Area	16	14	0.9	18%
Jan 9/74	Wabamun Open Area	10	5	0.5	20%
Nov 27+28/73	Sundance Open Area	31	217	7.0	48%
Nov 29/73	SW Portion Of Goosequill Bay Through Ice	23	34	1.47	17%
Dec 20+21/73	Shallow Areas Around The Perimeter Of The Lake	37	2	0.05	2.7%
Jan 22/74	Sundance Open Area*	30	1	0.03	3.3%

* This open area is larger than it was when sampled on November 27+28,1972 due to the starting of unit 2 of the Sundance Power plant.

the number of fish that had spawned in the area. The region out from the Wabamun discharge canal did not appear to be as important for spawning although a fairly high concentration of eggs was found there (Table 18).

Since no whitefish population estimates have been determined for Lake Wabamun, the spawning population of whitefish is not known and therefore the percentage of fish spawning in the open water area on the ooze substrate could not be determined. To obtain some estimate of the magnitude of the situation, the estimate of the fish spawning near the Sundance power plant on the ooze substrate was compared to the annual yield of whitefish taken from the lake. Lane (1970) estimated from the creel census that between November and May of 1968-69, sports fishermen removed approximately 79,200 lake whitefish. The commercial yield for the same year was approximately 22,800 whitefish giving a total yield in the neighborhood of 102,000 fish. Using the estimate of 8,800 females and 8,800 males (on the assumption of a 1:1 sex ratio) as spawning in front of the Sundance plant, the percentage of the whitefish spawning in the Sundance open area would be approximately 18% of the annual yield. Since the spawning population would have been larger than the annual yield (or else the fishery would collapse), the percentage of the spawning population spawning on the ooze substrate in the heated areas would be less than 18%. Although the above estimates are very crude and are based on limited data, they do give some indication of the

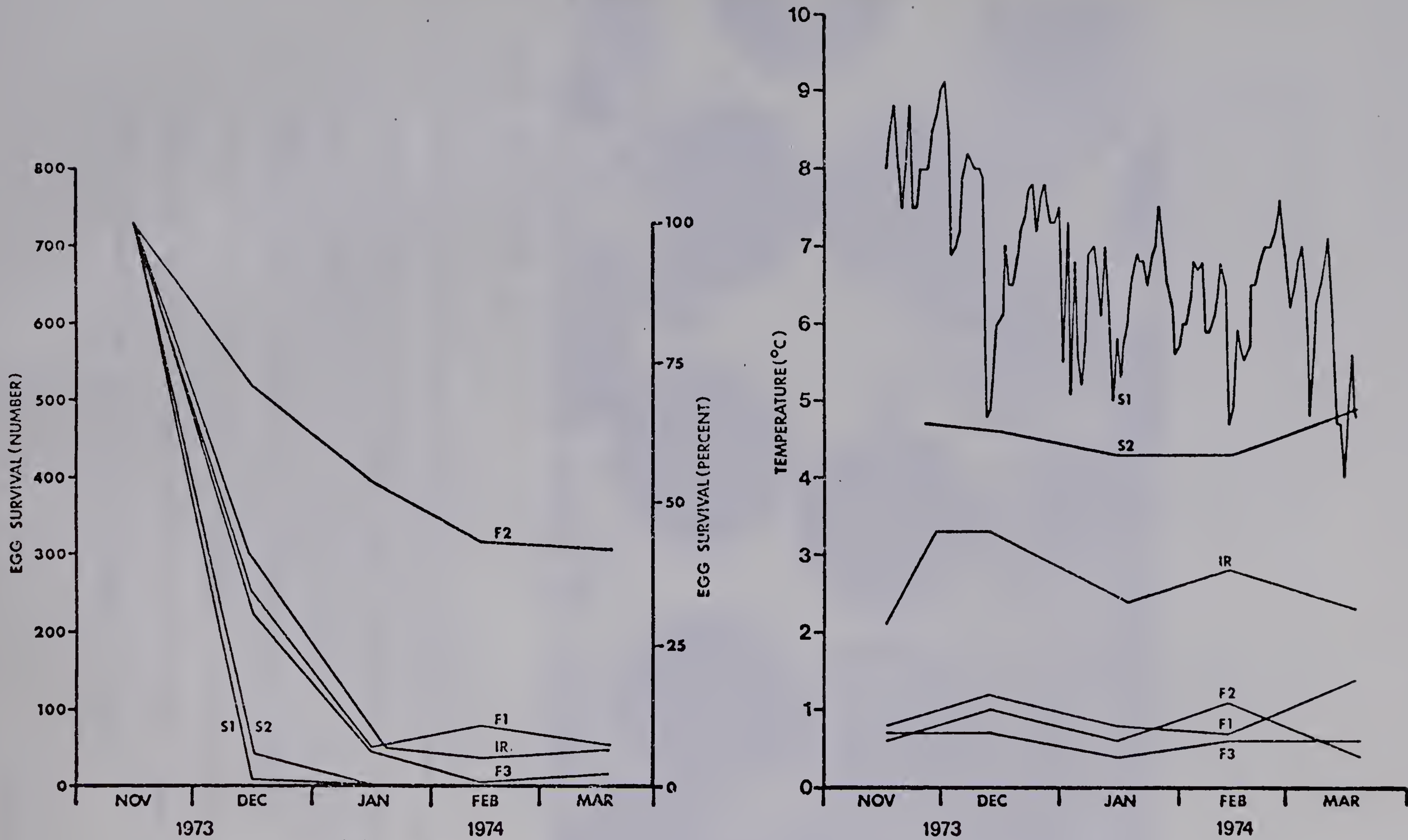
utilization of the heated areas for spawning.

Price (1940) showed that the optimum temperature for lake whitefish egg incubation was near 0.5° C and that 6° C was the maximum temperature at which normal development characteristically occurs (Table 19). The whitefish eggs incubated at site S1 (Figure 5) during this study showed the lowest survival (Figure 18a). This could be attributed partially to the higher incubation temperatures at this site (9.1°C - 4.0°C; $\bar{x}$=6.69°C) compared to the other incubation sites (Figure 18b). Temperature alone, however, cannot completely explain the high mortality at site S2 where the eggs were incubated below Price's 6° C maximum temperature (Figure 18b). Incubation on an ooze substrate probably contributed greatly to the high mortality. The low survival at the control site F3 where the eggs were also incubated on an ooze substrate but at a low temperature substantiated the detrimental effects of the ooze. Hutchinson (1957) suggested that a microzone of oxygen deficient water exists above the mud-water interface because of bacterial respiration. Hall (1925) reported that an oxygen concentration of 0.6 cc/l (0.9 mg/l) was below the threshold for lake whitefish egg development and that none of his eggs incubated below these concentrations developed beyond the elongation of the tail bud. This is close to the stage at which many of the eggs at site S1, S2, and F3 died (Plate 10). It is conceivable then, that the dissolved oxygen levels of the water around the eggs at site S1, S2 and F3 (all on an ooze substrate) could

Table 19. Egg mortality at different incubation temperatures.

(From Price, 1940)

MORTALITY	0.5°C	2.0°C	4°C	6°C	8°C	10°C
a) Prior to Hatching stage	26.25	38	40.0	27.5	34.4	63.0
b) During Hatching	1.08	4	1.4	14.0	46.8	36.4
c) Total Mortality	27.3	42	41.4	41.5	81.2	99.4
d) Survival	72.6	58	58.6	58.5	18.8	0.6
e) Estimated embryos alive at hatching stage that were abnormal (%)	0	0	1	10	25	50



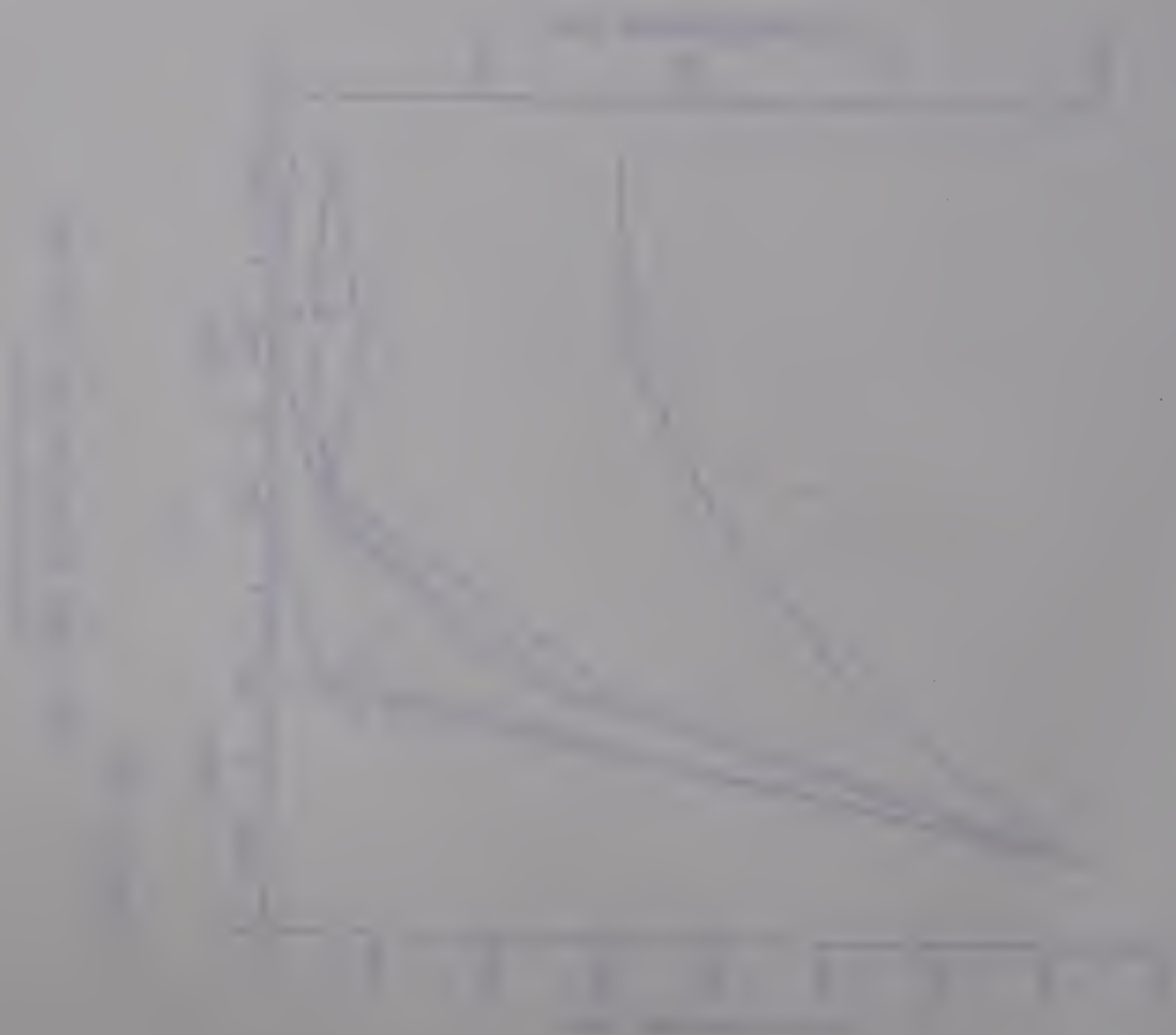
(A)

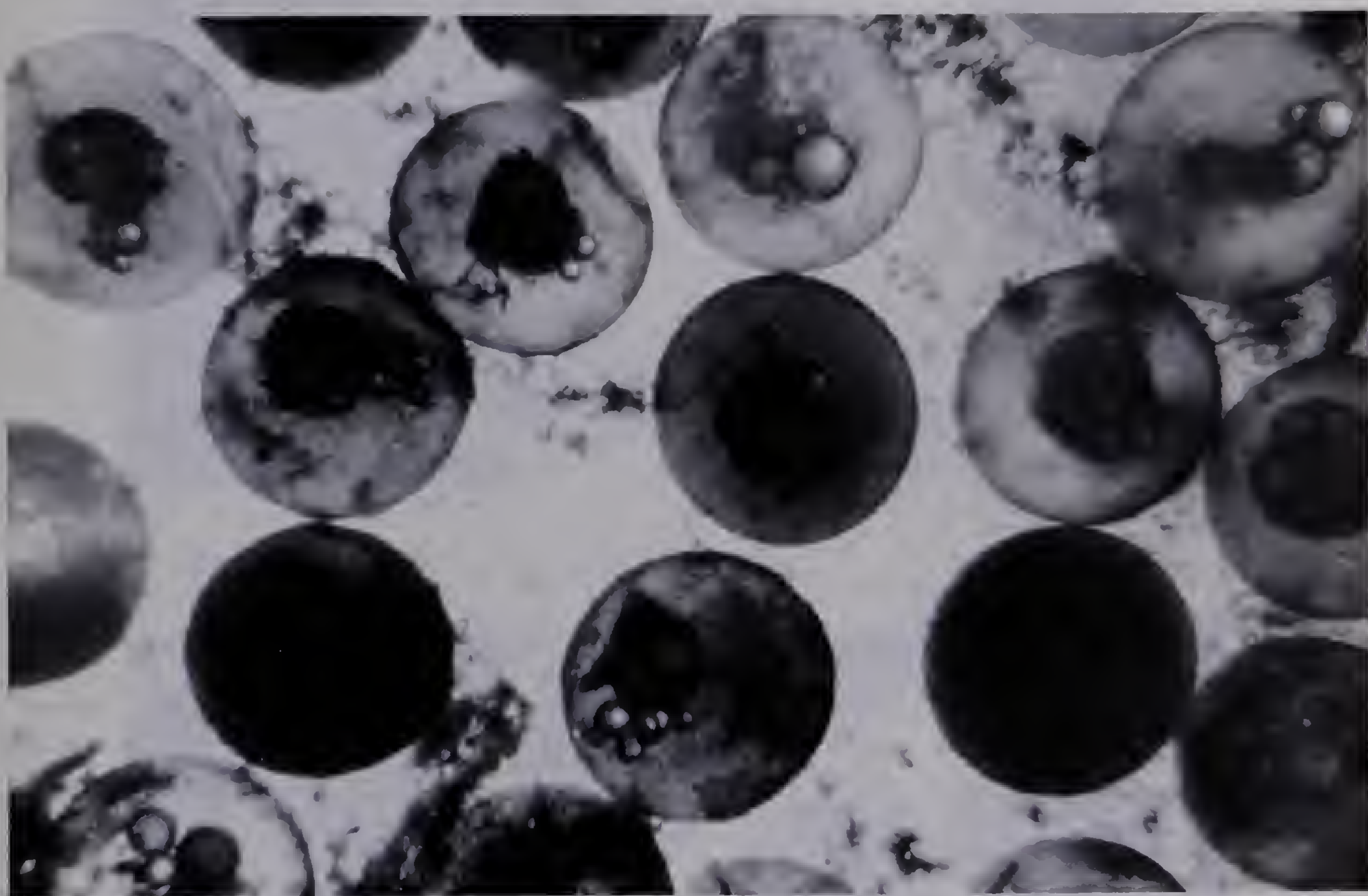
(B)

Figure 18:

(A) Egg survival at the egg incubation sites

(B) Bottom temperatures at the egg incubation sites



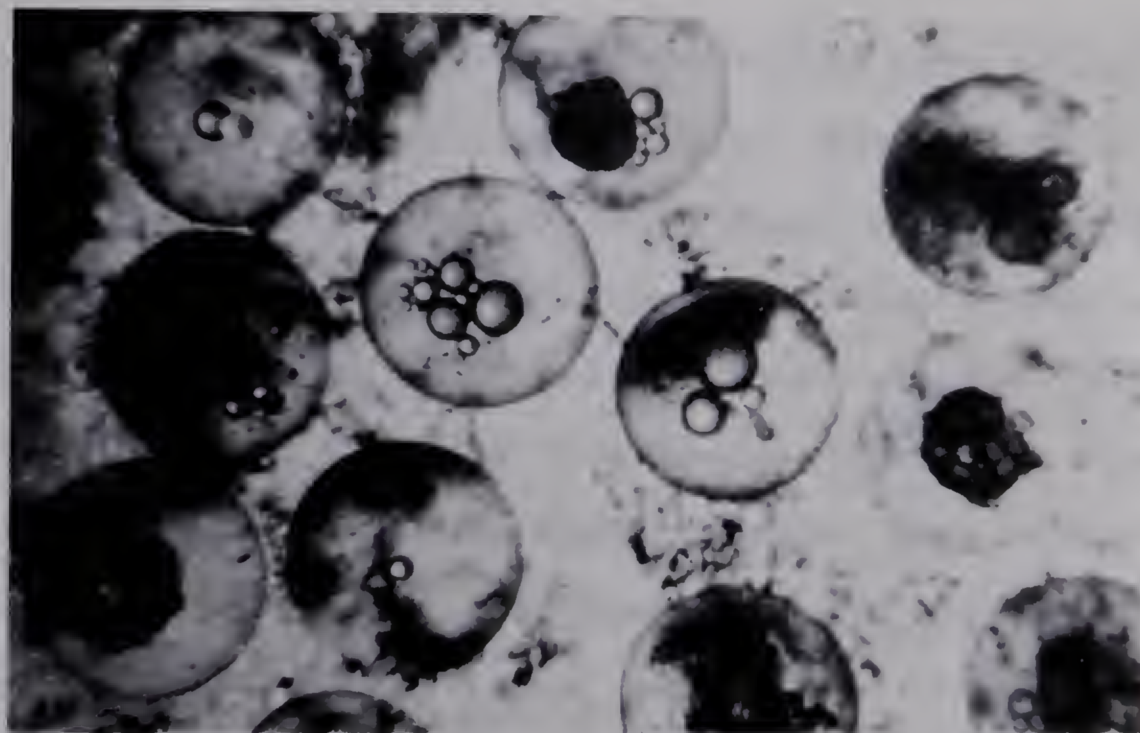


A) Site S1 (Ooze Substrate)

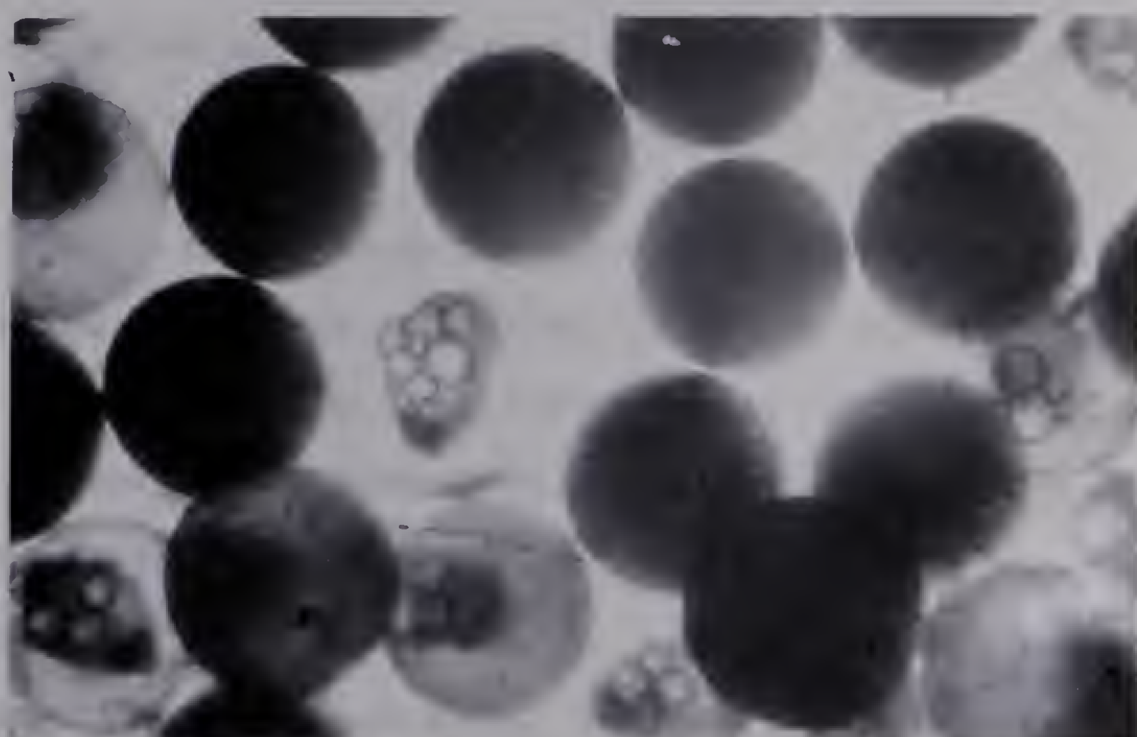
Plate 10. Dead lake whitefish eggs incubated in enclosed trays on an ooze substrate in Lake Wabamun. A) Site S1 in the heated area near Sundance. B) Site S2 also in the heated area at Sundance but farther away from the discharge canal. C) Site F3 one of the control sites near Fallis. Note the bits of fungus and silt on the eggs from Site S1 and S2. These eggs were retrieved from the lake on December 17, 1973.

(continued)

Plate 10 (continued)



B) Site S2 (Ooze Substrate)



C) Site F3 (Ooze Substrate)

have decreased to below the critical level during part of the incubation period.

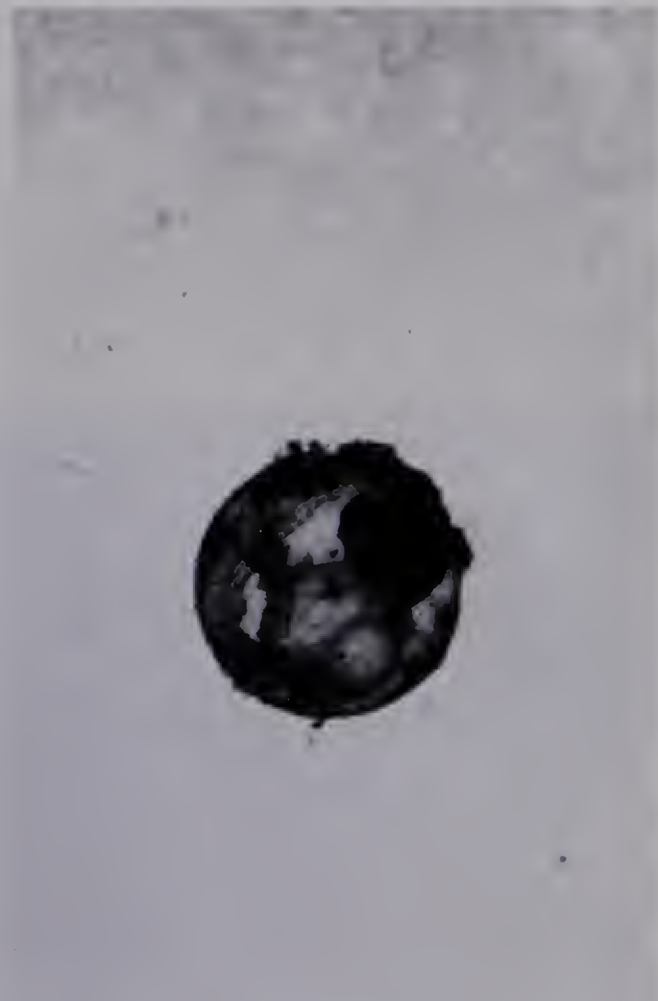
The five egg incubation trays that were set on top of the empty trays to keep the eggs above the substrate at site S1 did not contain any viable eggs when retrieved on February 15, 1974. The five trays that were on top of other trays but also under the polyethylene at the same site contained 11 eyed eggs and 12 live fry (Plate 11) along with numerous dead eggs and eggs covered with fungus. This suggests that siltation contributed to the high mortality of the eggs incubated in that area. The extent to which siltation affected the eggs incubated at sites under the ice was not determined. Siltation likely would not be as great under the ice since ice-cover prevents winds from causing wave action which stirs up the lake.

Large algal growths occurred on the egg incubation trays and on the eggs at sites S1 and S2 in the open water. The respiration of the algae during dark periods also may have reduced the oxygen levels below that required for egg development. These growths may have partially restricted the circulation of water above the eggs and reduced gas exchange. No prominent algal growths were noted at the other sites.

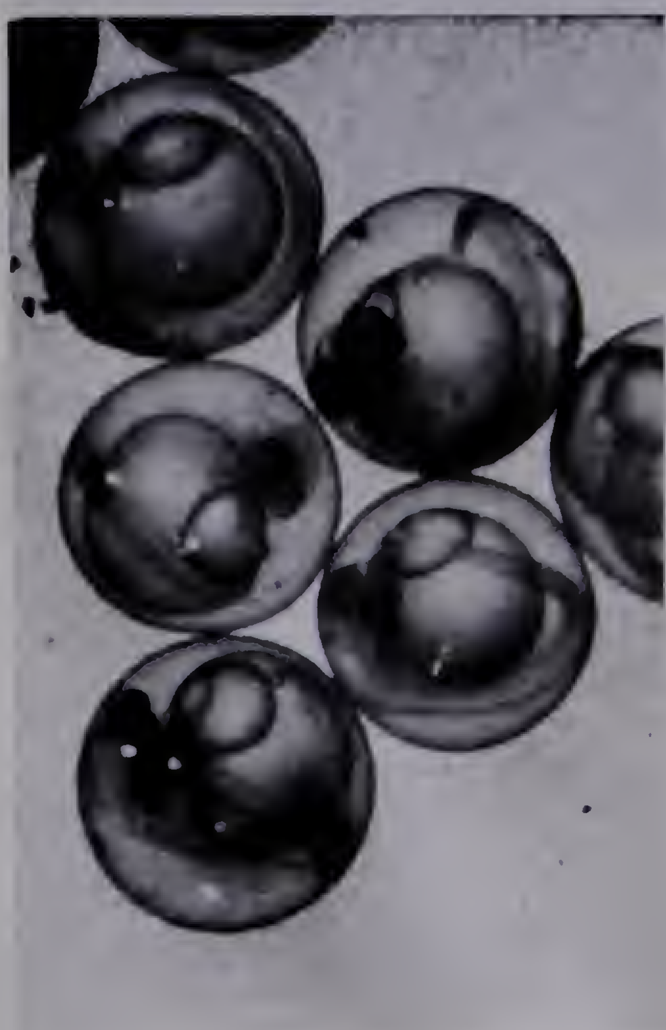
Large growths of the fungus Saprolegnia sp. (Plate 12) were observed on the eggs at the open water sites with lesser amounts on the eggs at the IR2 site. Only occasional

Plate 11. Live lake whitefish fry and eggs from egg incubation trays retrieved from Lake Wabamun on February 15, 1974. A) Live fry Site S1 (under polyethylene). B) Live egg from Site S1 (under polyethylene). Note the large amount of silt on the eggs. C) Live eyed eggs from Site F3 (Ooze Substrate). D) Live eyed eggs from Site F2 (Sand Substrate).

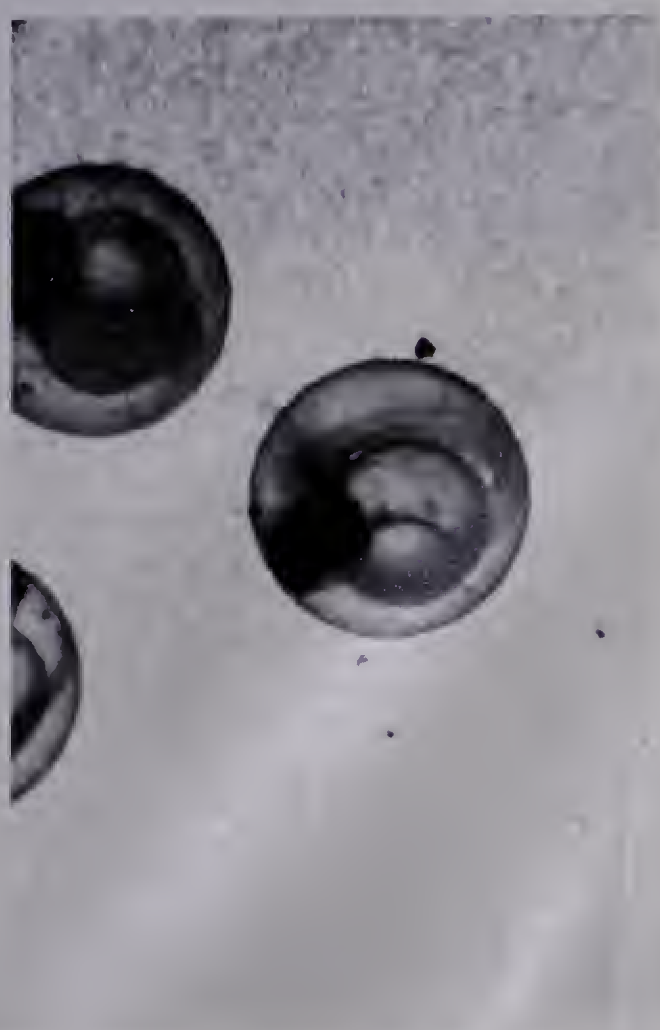
(A)



(B)



(C)



(D)

Plate 12. Dead lake whitefish egg covered with the fungus Saprolegnia sp.

small growths of fungus were noted on the eggs incubated at the control sites at Fallis. Hall (1925) reported that *Saprolegnia* grew very rapidly on dead eggs and also matted large numbers of live eggs together, killing them in a day or two. Hall also stated that higher temperatures were more favorable to the fungal growth. This may partially explain the very high mortality at sites S1 and S2 in the open water (higher temperatures) and the lesser mortalities at the lower temperature sites on the Indian Reserve (IR1, IR2, IR3) and at Fallis (F1,F2,F3). Temperature therefore, is also important due to its indirect effect of increasing fungal growth.

Although at present the heated water does not keep the rocky shoal area along the Indian Reserve ice-free throughout the winter, it does affect the temperature near the bottom, keeping it higher than that normally found at similar depths and over similar substrates in the west end of the lake (Table 20). This appears to be caused by a warm water current moving from the Sundance outlet over the shoal. Observations made during the winter through holes in the ice above the shoal area support the existence of such a current since zooplankton and bits of detritus were passing under the holes in a north-westerly direction at a considerable speed. Leaves of *Elodea* also were observed floating under the ice moving in a similar direction. This is further evidence that the current exists, since *Elodea* grows mainly in the heated areas of the lake (Allen, 1973).

Table 20. Temperature at a depth of 6 ft. (1.8 m) at various places around the lake on December 21, 1973.

PLACE	SUBSTRATE	TEMPERATURE
Sailing Club	Rock	1.8°C
1/2 mile East of Fallis	Sand and Ooze	0.9°C
Fallis	Sand	1.0°C
Fallis Point	Sand and Ooze	1.8°C
West of Sundance Inlet	Sand	1.2°C
Indian Reserve Shoal	Rock, gravel	3.0°C

A possible explanation for the current is that the heated water is discharged in a south-eastward direction into Indian Bay and when it comes near the south-east shore of the bay, it may be deflected northward along the east shore and over the rocky shoal along the Indian Reserve. This may also be tied in with a circulation of water between the discharge and intake canals.

Whitefish eggs incubated at higher temperatures were further developed than those incubated for the same period of time at the lower temperatures (Table 21). The time to hatching also decreased with increased incubation temperature (Table 22). Price (1940) showed that the total incubation period to hatching increased from 29.6 days at 10° C to 141 days at 0.5° C. Bidgood (1972) reported similar results. Hall (1925) showed that the shorter the incubation period (i.e. the higher the temperature), the smaller the size of the fry produced. These smaller fry had less energy and consequently less stamina and died sooner without food than those fry from eggs that had been incubated for a longer period of time at a lower temperature. This suggests that lake whitefish eggs incubated at higher temperatures than normal may hatch under the ice at a time when food supply is low. Since the smaller fry would have less energy and stamina, they would need food sooner than the larger fry that hatch later. A small number of the whitefish eggs incubated on the rocky shoal area at sites IR1 and IR2 had hatched before the incubation trays were retrieved on March

Table 21. Time to the eyed stage of development at the various incubation sites. The approximate percentage of the viable eggs that were eyed is given in brackets. (Eyed eggs '■'; Not eyed 'X'; No trays retrieved '*'; No viable eggs '#'). For temperature information, see Figure 18b.

SITE	DEC 1963	JAN 1974	FEB 1974
S1	■ (50%)	#	■ (100%)
S2	■ (30%)	■ (100%)	#
IR1	X	■ (100%)	■ (100%)
IR3	X	*	*
F1 Fallis (Rock+Sand)	X	■	■ (100%)
F2 (Sand)	X	X	■ (90%)
F3 (Ooze)	X	X	■ (100%)

Table 22. Samples that contained fry when retrieved from lake. (Fry '■'; No Fry 'X'; No Trays Retrieved '*'; No Viable eggs '#'). All eggs fertilized on Nov. 15, 1973 with the exception of IR1).

SITE	DEC	JAN	FEB	MARCH
S1	X	#	X	#
S2	X	X	#	*
S1 (eggs under polyethylene)	*	*	■	*
IR1 (fertilized on Oct. 19,1973)	*	*	*	■
IR2	X	X	X	■
IR3	X	*	*	*
F1 (Rock+Sand)	X	X	X	X
F2	X	X	X	X
F3 (Ooze)	X	X	X	X

19, 1974 while at the same time, no fry were observed in trays retrieved at the control sites near Fallis. The bottom temperatures at IR1 was 4° C and at IR2 it was 2.3° C. The small numbers of fry and the unhatched eggs retrieved at sites IR1 and IR2 in March were taken out of the incubation trays and placed into vials for transport to shore. By the time the vials had been taken to shore, all but four of the eggs from the trays at IR1 and 45 of the eggs from the trays at site IR2 had hatched. This sudden hatching may be attributed to the increase in the temperature of the water that the eggs were in as they were taken to shore. Bidgood (1971, pers. comm.) also noted hatching of lake whitefish eggs when the temperature of water in incubation jars was suddenly increased. It is also possible that mechanical stimulation contributed to the sudden hatching noted in this study. The ice cover at these sites melted approximately 2-3 weeks later. This indicates that very few eggs would hatch under the ice and it appears that the majority of the eggs develop only to a certain stage and are then stimulated to hatch as the temperature of the water rapidly increases. Such an increase in water temperature would be associated with the disappearance of the ice cover. This would subsequently be followed by an increase in the planktonic food organisms (Figure 11). A greater number of the lake whitefish eggs had hatched before being retrieved at site IR1 than at IR2 (Table 22). Eggs at site IR1 had been placed in the lake on October 19, 1973 when the water temperature

was 7.5° C. Eggs at site IR2 had been placed in the lake on November 18, 1973 when the water temperature was 2.1° C. All but four of the eggs from IR1 had hatched by the time they had been taken to shore indicating that they were slightly further developed than those from IR2. Although the heated discharge from the power plants appeared to increase the rate of development in the whitefish eggs causing them to hatch earlier, the heated water also caused the ice-cover in the east end of the lake to disappear earlier. Increased zooplankton production would probably quickly follow the disappearance of the ice due to increased water temperatures. This earlier hatching and earlier ice breakup may give the fry in the area a 'head start' in growth.

On April 25, 1973, a sample of 14 lake whitefish fry were caught in the open water area over the rocky shoal area along the Indian Reserve. The average length of the fry was 13.4 mm with a range from 11.7 mm to 17.5 mm. The only recognizable food in the stomachs of these fry was Cyclops bicuspidatus thomasi with the exception of one Chaoborus sp. larvae that was 4 mm in length. Hart (1930) reported lake whitefish fry of similar size feeding mainly on Cyclops sp. with some cladocerans also being eaten. Hall (1925) reported that lake whitefish fry survived up to 25 days by living off their yolk sac. The few fry that hatch under the ice in late March should therefore be able to survive without food until well after the ice disappears. Starvation would not likely occur since the biomass of copepods which appeared to be the

major food of the fry was quite high in March (Figure 11).

4. LAKE WHITEFISH MOVEMENTS

The tagging and recapture locations for 22 tagged lake whitefish are shown in Figure 19. A similar figure for tagged northern pike is shown in Appendix II. All but one of the lake whitefish returned were tagged at a fish trap that had been placed in the channel joining Goosequill Bay with the remainder of the lake. Six of the recaptured fish were taken within 200 m of the location where they had been tagged while the remainder were captured at various locations in the lake. One fish moved approximately 7.5 km to a position along the south shore of the lake within 8 days while another was across the lake at Fallis 26 days later when recaptured. Most of the fish were recaptured more than six months after tagging since there is very limited fishing pressure for lake whitefish during the summer months.

The results of this tagging program indicate that although some of the fish remained in the area close to where they were tagged, many dispersed throughout the lake. This may be due to the fact that at the time when most of the fish were tagged, they were moving into Goosequill Bay, probably to feed on the abundant aquatic invertebrates in the area. Stomach analysis of the lake whitefish taken in the area at this time revealed that large numbers of

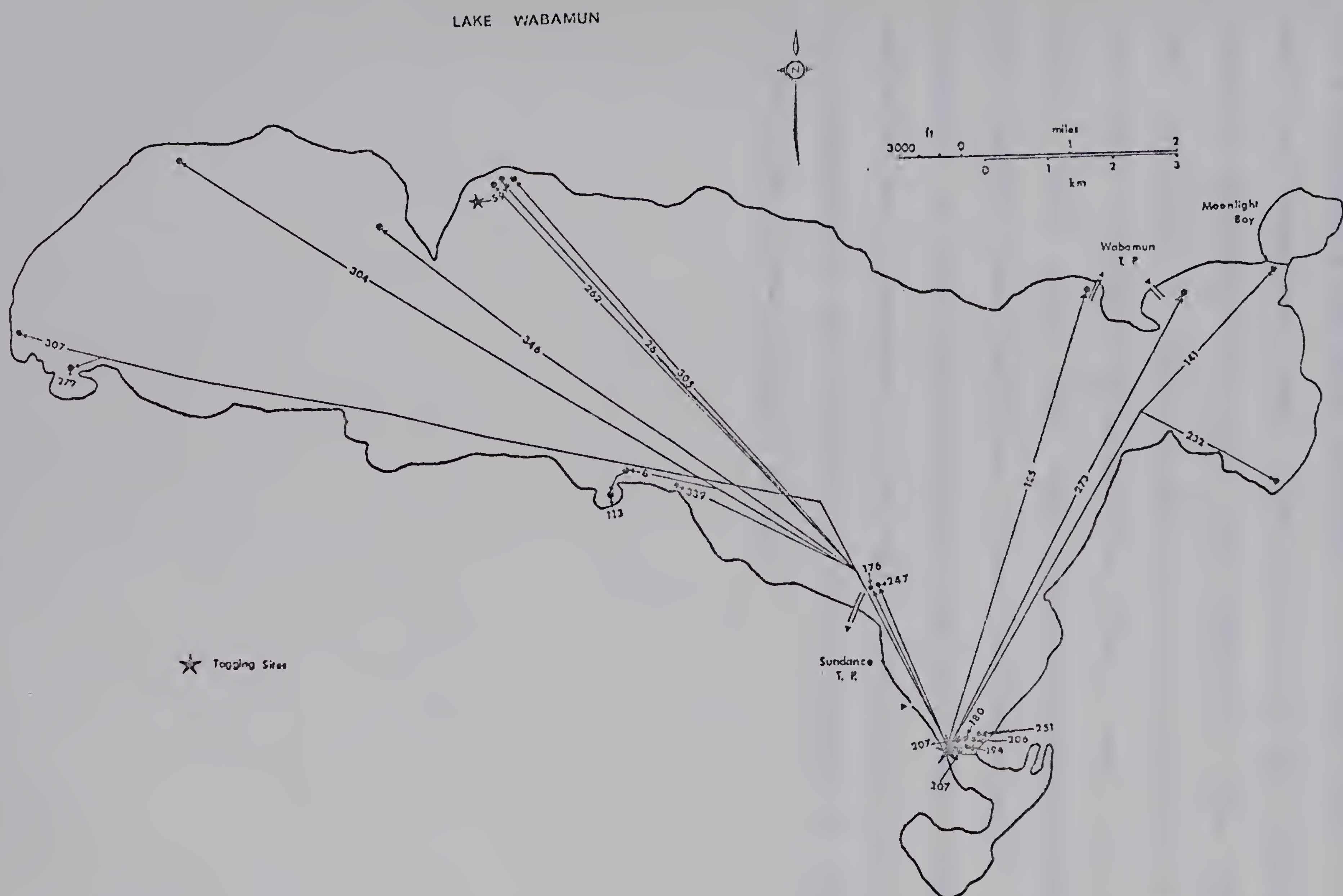


Figure 19. Tagging and recapture locations for 22 lake whitefish tagged between January 23, 1973 and June 4, 1973 The number of days between the date of tagging and the date of recapture is shown for each fish.

amphipods and damselfly larvae were being consumed. Since the fish likely had been attracted into the area to feed, it would be expected that upon their exit they likely would disperse throughout the lake. The length of time that the fish remained at any one place in the rest of the lake is not known. It should be noted that since most of the tag returns were from fish that had been tagged within a one month period, one should not draw conclusions as to the movements of the fish throughout the year. More research is needed on the movements of the whitefish in the lake before any conclusions can be drawn as to the length of time spent by the fish in the various areas.

SUMMARY OF RESULTS

1. The standing crop of benthic invertebrates generally was much greater at the WW site than at the CW site (Table 7). Tendipedidae larvae were the most abundant organism at both sites.

2. The standing crop (biomass) of zooplankton exhibited a spring and an autumn pulse with the latter occurring earlier at the WW site than at the CW site (Figure 11). This may also be true for the spring pulse but the infrequency of sampling would make it difficult to detect. Cladocerans were prevalent throughout the winter at the WW site but not at the CW site. Copepods are fairly abundant throughout most of the year at both sites.

3. The diet of lake whitefish in the heated areas was quite different from that in the unheated areas. The predominant food item in the diet of the lake whitefish at the WW site was <u>Elodea</u> shoots (Figure 9). Gastropods and tendipedids were abundant in the diet during the spring and summer. Cladocerans were eaten during the winter as well as in the spring at the WW site whereas at the CW site, they were eaten only during the spring indicating the greater abundance of cladocerans in the heated areas during the winter. The predominant food

items in the diet of the CW fish throughout most of the period studied were tendipedid larvae and pelecypods. Small perch were heavily preyed upon during October and November.

4. The small whitefish at the CW site fed mainly on planktonic organisms whereas the larger fish ate mostly macrobenthos and small fish (Figure 10). At the WW site, the smaller and medium sized fish ate a variety of food with Elodea shoots usually being the largest contributor. The larger fish fed to a greater extent on gastropods.

5. The lake whitefish at the WW site had fuller stomachs between February and June of 1973 whereas the CW fish had fuller stomachs during August, October, November and December of 1972 (Table 6). The heavy predation on small perch by the CW fish during the fall of 1972 was probably important in maintaining the fish in good physical condition during the spawning season.

6. The mean condition factor of lake whitefish from the WW site was significantly greater than that at the CW site during June and September of 1972 and May and June of 1973 (Table 8). The CW fish had a greater condition factor during July of 1972. The mean condition factor of the females in the heated zone was greater than in the coldwater zone during June and September of 1972 and May

and June of 1973. The CW female whitefish were never found to be in better condition than the ones at the WW site (Table 9). Lake whitefish sampled in June of 1973 had a larger mean condition factor than did fish sampled in June of 1972 (Table 10).

7. There was no consistent difference between the length-weight relationships of lake whitefish in the heated and non-heated areas (Table 11).

8. Most of the female whitefish do not spawn until they are 5 years old although a small percentage spawn when they are only 4 years of age and a few do not spawn until they are six years old (Table 12). A large percentage of the 4 year old male whitefish spawn and all of the 5 year olds that were sampled were mature.

9. No significant differences were noted between the fecundities of the lake whitefish sampled at the two sites (Figure 15; Figure 16).

10. Spawning took place from early to mid October until early December when the water temperatures ranged from 9°C to 1°C.

11. The mean value of the gonad weight to body weight ratio (GSI) was greater for the fish sampled at the WW site

during June, late August and September of 1972 and during March, May, June and September of 1973 (Table 14). Fish from the CW site were never found to have a significantly greater GSI value than at the WW site. This indicates that the lake whitefish in the heated areas may have spawned earlier although this was not proven. This also indicates that the fish in the heated area with their increased metabolism resorbed their residual eggs faster and started building up new ovarian tissue earlier than the fish at the CW site. Although the ovary development of the CW fish appeared to catch up to that of the WW fish during the summer, the WW fish again moved ahead from late summer until the time of spawning. The difference in the time of spawning is not known. Any factor that causes the fish to spawn earlier than normal would be detrimental since incubation at the higher water temperatures would cause increased mortality of the eggs and a greater number of abnormalities in the embryos (Table 19). Early spawning at a warmer water temperature would also cause increased development and, therefore, would result in earlier hatching.

12. Approximately 72.6% of the total rock and sand substrate which is the prime lake whitefish spawning habitat is found in the east end of the lake (Table 17). Only 22.5% of the sand substrate which is less suitable for spawning is found in the east end of the lake.

13. Approximately 65.2% of all of the rock and sand substrate is located on a shoal along the Indian Reserve on the east side of Indian Bay. The temperature of the water along the bottom of this shoal was found to be higher than at the control sites. This has been attributed to a warm water current in the area related to the heated discharge from the Sundance power plant.

14. Large numbers of lake whitefish eggs were found on an ooze substrate in the ice free areas of both power plants (Table 18). It appeared that the heated water discharge had stimulated some whitefish to spawn in these areas since eggs were not found on similar substrate in the coldwater areas of the lake.

15. Lake whitefish eggs incubated at sites in the heated area at Sundance showed very poor survival while eggs incubated on a sand substrate at Fallis showed the greatest survival (Figure 18a). The eggs incubated in areas with the highest water temperature (Figure 18b) showed the least survival (Figure 18a). Eggs incubated at a low temperature but on an ooze substrate at the control sites also showed poor survival.

16. Lake whitefish eggs incubated in the heated area at Sundance above the ooze substrate and under a

polyethylene covering, showed better survival than eggs that had been incubated either above or on the ooze substrate without a polyethylene covering indicating that siltation contributed to the high mortality of the eggs in the heated area.

17. Lake whitefish eggs incubated at higher temperatures had larger growths of fungus associated with them than did eggs incubated at lower temperatures. Since the fungus kills many of the eggs and since higher temperatures are more favorable to fungal growth, any increase in the incubation temperature due to the heated discharges would also affect the survival of the eggs by increasing fungal growths.

18. Lake whitefish eggs incubated at higher temperatures showed increased development of the embryos and earlier hatching compared to eggs incubated at lower temperatures (Tables 21 and 22). Some lake whitefish eggs incubated on the large shoal area along the Indian Reserve hatched under the ice. However, a sharp increase in water temperature (which would occur as the ice cover melts) appeared to be an important stimulus for hatching. The ice-cover in the east end of the lake (which includes the rocky shoal area which is the major spawning area) melted earlier than the ice-cover on the rest of the lake due to the heated discharges from the two power plants. Because

of the early disappearance of the ice-cover in this area, it is doubtful that many of the lake whitefish eggs had hatched under the ice. The fairly large numbers of copepods found in both the heated and unheated areas during late winter (Figure 11) would probably be sufficient food to maintain any fry that had hatched out under the ice.

19. The majority of lake whitefish tagged during late-May and June, 1973, in the canal joining Goosequill Bay and Indian Bay moved from the area where they were tagged and dispersed throughout the lake (Figure 19). Six of the tagged fish were captured close to where they were tagged indicating that a number of fish remained in the area or else had returned there possibly to enter the southern portion of the bay the following spring. No data were obtained as to the movements of lake whitefish into or out of the heated areas or as to the length of time spent in the heated areas.

CONCLUSIONS AND RECOMMENDATIONS

1. The discharge of heated water from the Sundance thermal electric power plant should be halted as soon as possible. The reason for this recommendation is as follows:
   a. Large numbers of lake whitefish are being stimulated to spawn on an ooze substrate in the heated area in the vicinity of the discharge. These eggs show very poor survival.
   b. At present with units 1 and 2 in operation, the thermal plume does not reach the rocky shoal area along the Indian Reserve which is the most important lake whitefish spawning area of the lake. However, a current of warm water which probably originates from the Sundance discharge maintains the bottom water temperature higher than normal. This higher temperature increases egg mortality by promoting fungal growths and increases the rate of egg development causing the eggs to hatch earlier.

2. The thermal discharge from the Wabamun power plant should be maintained at its present state. The reasons for this recommendation are as follows:
   a. Although some lake whitefish are stimulated to spawn in the heated area, the numbers do not appear to be as large as at the Sundance heated area.
   b. The thermal plume does not reach any major spawning

areas.

c. The standing crop of benthic invertebrates and invertebrates attached to the submerged macrophytes is greater in the heated areas than in the unheated areas. This results in greater food availability for the lake whitefish which would help maintain a large standing crop of whitefish.

3. Weed cutting practices in Lake Wabamun should be stopped. The reasons for this recommendation are as follows:

   a. Removal of the submerged macrophytes results in removal of lake whitefish food organisms. These include snails (Gastropoda) and caddis fly larvae (Trichoptera) as well as shoots of the plant *Elodea canadensis*, all of which are important items in the diet of the lake whitefish in the area.

   b. Removal of the weeds not only results in the removal of the food organisms attached to them, but also in the removal of the habitat suitable for these invertebrates. Therefore, there would be lower production of these food organisms.

   c. Removal of the weeds and the associated lake whitefish food organisms would result in either decreased growth of the fish or else a decrease in the number of the fish that the lake can maintain.

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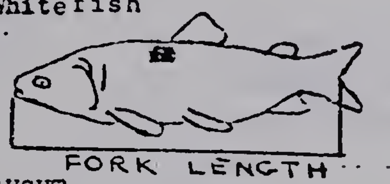
Appendix 1. Tag return form.

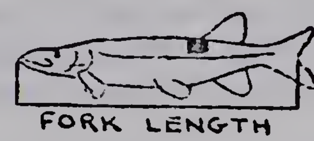
TAGGED FISH

In order to help understand the effects of heated effluents on fish in Lake Wabamun, a tagging program has been undertaken. If you catch a tagged fish, please fill in the information below.

Lake Whitefish



Northern Pike (Jackfish)



DATE CAUGHT: ____________________

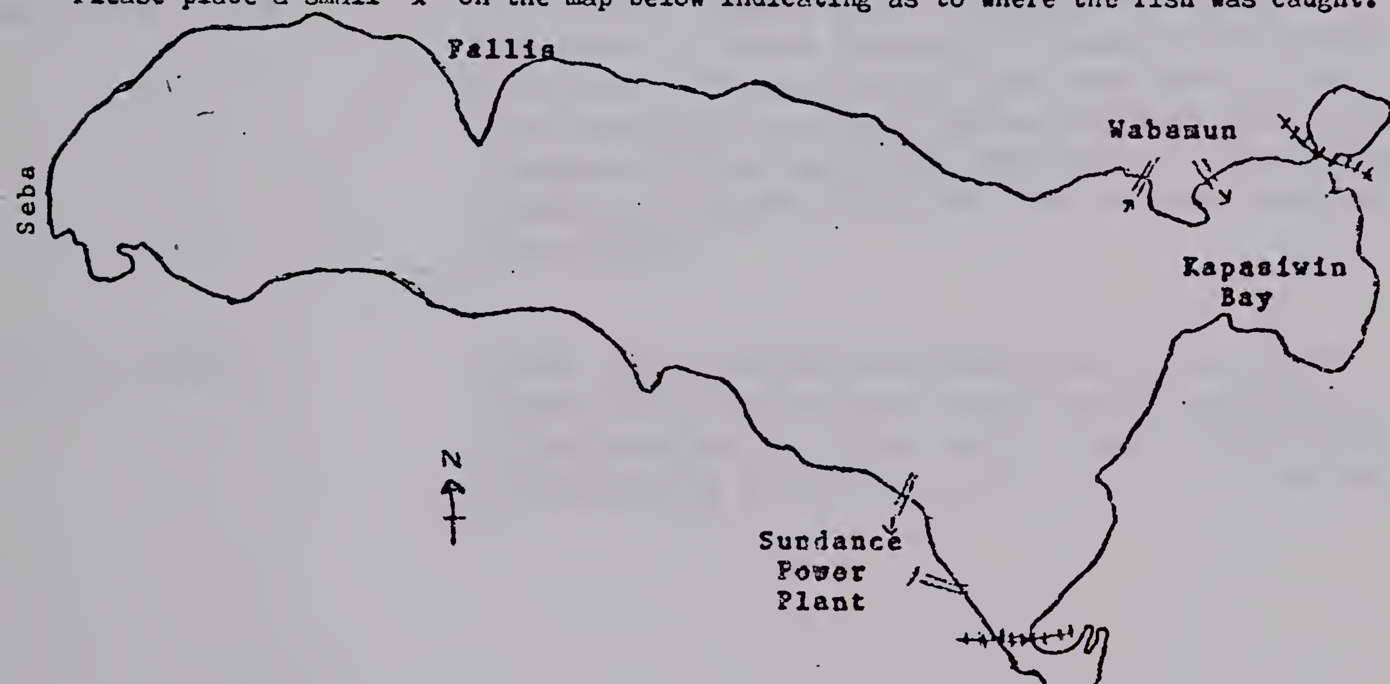
SPECIES of FISH: ____________________

TAG NUMBER: ____________________

FORK LENGTH: ____________________ (perferably in centimeters)

** Dark area indicates area where scale sample (10-15 scales) should be taken.

Please place a small 'x' on the map below indicating as to where the fish was caught.



Please give a verbal discription in detail as to where in the lake the fish was caught.

____

____

YOUR NAME: ____________________

ADRESS: ____________________

____

PHONE: ____________________

PLEASE MAIL THIS SHEET ALONG WITH THE TAG AND SCALE SAMPLE (folded in a separate sheet of paper) TO:

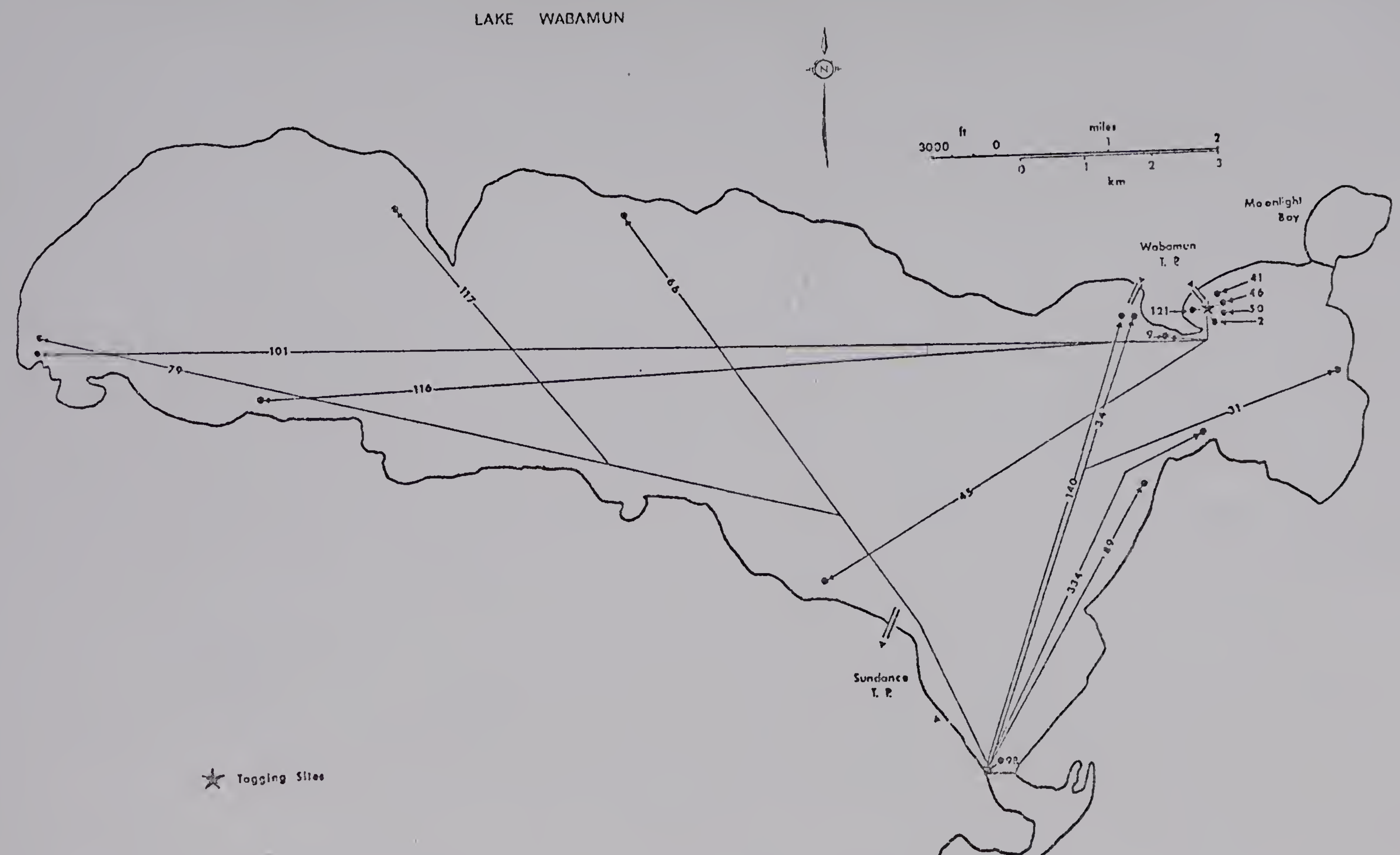
Gary R. Ash
Department of Zoology
University of Alberta
Edmonton

A letter giving the history of the tagged fish will be returned to you. It is only through your cooperation that this study can be a success!

APPENDIX 2

Some observations relating to the spawning of northern pike and white suckers in Lake Wabamun.

March 26, 1973	- First ripe male northern pike and male white sucker were noted. The surface temperature was 7.8°C and the bottom temperature was 5.2°C.
March 27 and 29, 1973	- Numerous ripe male northern pike, male suckers, and some ripe female suckers were captured.
March 30, 1973	- One spent female pike was captured which appeared to have spawned at least 1 - 2 weeks earlier. Three females that were very close to spawning, two spent male northern pike, and numerous ripe male pike were noted. The surface temperature was 8.4°C and the bottom temperature was 5.8°C.
May 16, 1973	- Nine spent males, fourteen ripe males, five spent females and two ripe female northern pike were noted. The water temperature at the surface was 24°C and it was 11.3°C at the bottom.



Appendix 3. Movements of tagged northern pike. The number of days between the date of tagging and the date of return is indicated for each fish.